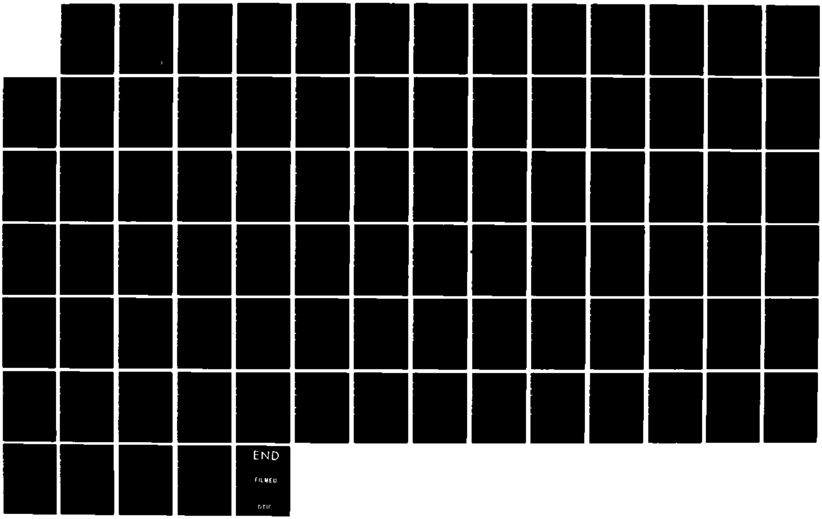
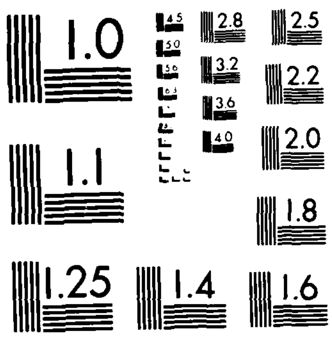
AD-A153 471 FIELD VALIDATION OF STATISTICALLY-BASED ACCEPTANCE PLAN FOR BITUMINOUS AI..(U) CLEMSON UNIV S C DEPT OF CIVIL ENGINEERING J L BURATI ET AL. MAY 84 1/1

UNCLASSIFIED DOT/FAA/PM-84/12-VOL-3 DTFA01-81-C-10057 F/G 1/5 NL




1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

2

DOT/FAA/PM-84/12,III

Program Engineering
and Maintenance Service
Washington, D.C. 20591

Field Validation of Statistically Based Acceptance Plan for Bituminous Airport Pavements

Volume 3—Statistical Analysis of Three Methods for Determining Maximum Specific Gravity of Bituminous Concrete Mixtures

James L. Burati, Jr.
James D. Seward, Jr.

Department of Civil Engineering
Clemson University
Clemson, South Carolina 29631

May 1984

This Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/PM-84/12, III	AD-A153 471	

4. Title and Subtitle	
FIELD VALIDATION OF STATISTICALLY-BASED ACCEPTANCE PLAN FOR BITUMINOUS AIRPORT PAVEMENTS VOLUME 3 - STATISTICAL ANALYSIS OF THREE METHODS FOR DETERMINING MAXIMUM SPECIFIC GRAVITY OF BITUMINOUS CONCRETE MIXTURES	5. Report Date: MAY 1984
	6. Performing Organization Code
7. Author(s): Burati, J.L. and Seward, J.D.	8. Performing Organization Report No.
9. Performing Organization Name and Address: Department of Civil Engineering, Clemson University, Clemson, SC 29631	10. Work Unit No. (TRAIS)
	11. Contract or Grant No.: DTFA01-81-C-10057
12. Sponsoring Agency Name and Address: U.S. Department of Transportation, Federal Aviation Administration, Program Engineering and Maintenance Service, Washington, DC 20591	13. Type of Report and Period Covered: FINAL REPORT
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract
Five replicates of asphaltic concrete at five alphalt contents were produced and tested to compare maximum specific gravities determined by individual constituents, by solvent immersion, and by ASTM D-2041. The effects of variations in asphalt content on the maximum specific gravities obtained by the three methods were also considered.

A statistically significant difference was found to exist between the solvent immersion and ASTM D-2041 methods at all five asphalt contents; whereas, no significant difference was found between the solvent immersion and individual constituents methods. There was a significant difference between the ASTM D-2041 method and individual constituents methods. This difference varies with asphalt content.

Since the solvent immersion and ASTM D-2041 methods provide statistically different results, it is not appropriate to allow the use of both methods in the same specification unless separate acceptance limits are used. It is recommended that the solvent immersion method be eliminated from use since the ASTM D-2041 procedures are much more commonly used. To avoid the use of a correction factor to convert the ASTM D-2041 values to equivalent individual constituents values, as is currently done, it is recommended that the maximum specific gravity for job mix formula determination be established by the ASTM D-2041 method.

17. Key Words	18. Distribution Statement
Air Vods, Specific Gravity, Acceptance Plans, Solvent Immersion, Individual Constituents, Pycnometer	This document is available to the U.S. public through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	86	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGMENTS

This research was sponsored by the Federal Aviation Administration. The authors are indebted to personnel of the Federal Aviation Administration Eastern Region for information concerning suitable projects.

The research described in this report was carried out under the sponsorship of the Federal Aviation Administration. However, the analyses of data and all conclusions and recommendations are the responsibility of the authors and may not necessarily reflect the official views or policies of the Federal Aviation Administration. This report does not constitute a standard, specification, or regulation.

TABLF OF CONTENTS

LIST OF TABLES

List of Tables (Cont'd.)

List of Tables (Cont'd.)

LIST OF FIGURES

PREFACE

This report presents the findings of a research project entitled "Field Validation of Statistically-Based Acceptance Plan for Bituminous Airport Pavements", Report No. DOT/FAA/PM-84/12, that was conducted to investigate the use of Marshall properties for acceptance purposes. The results of the research effort are presented in the series of reports listed below:

Burati, J.L., Brantley, G.D. and Morgan, F.W., "Correlation Analysis of Marshall Properties of Laboratory-Compacted Specimens," Final Report, Volume 1, Federal Aviation Administration, May, 1984.

Burati, J.L., Seward, J.D. and Busching, H.W., "Statistical Analysis of Marshall Properties of Plant-Produced Bituminous Materials," Final Report, Volume 2, Federal Aviation Administration, May, 1984.

Burati, J.L. and Seward, J.D., "Statistical Analysis of Three Methods for Determining Maximum Specific Gravity of Bituminous Concrete Mixtures," Final Report, Volume 3, Federal Aviation Administration, May, 1984.

Nnaji, S., Burati, J.L. and Tarakji, M.G., "Computer Simulation of Multiple Acceptance Criteria," Final Report, Volume 4, Federal Aviation Administration, August, 1984.

Burati, J.L., Busching, H.W. and Nnaji, S., "Field Validation of Statistically-Based Acceptance Plan for Bituminous Airport Pavements -- Summary of Validation Studies," Final Report, Volume 5, Federal Aviation Administration, September, 1984.

The application of multiple price adjustments is significantly more involved than the case when only one property, e.g., density, is considered. Since the Marshall properties (i.e., stability, flow and air voids) are physically related, they can be expected to be statistically correlated. If this is truly the case, then it may not be sufficient to treat each of the three properties individually. It is necessary to determine whether correlations exist among these properties, and whether such correlations should be considered when developing acceptance plans.

The objectives of the research described in the reports listed above include:

1. Review current methods for determining maximum specific gravity for use in air voids calculations for possible incorporation into the FAA Eastern Region P-401 specification,

2. Investigate the use of price adjustments when more than one characteristic is being used for acceptance purposes and recommend to the FAA potential procedures for dealing with multiple price adjustments,

3. Develop the procedures necessary to evaluate the performance of multiple properties acceptance plans,

4. Implement proposed Marshall properties acceptance plans on demonstration projects under field conditions, and

5. Attempt to correlate values of asphalt content and aggregate gradation with those from Marshall tests to determine whether or not correlations exist among these properties.

This report, Volume 3, presents the findings of an analysis of laboratory data for three methods for determining maximum specific gravity for use in air voids determination. The methods considered include: individual constituents, solvent immersion and ASTM D-2041.

The results of a laboratory analysis and an analysis of field data for the correlation among the Marshall properties are presented in Volumes 1 and 2, respectively. How correlations can be considered in the development of multiple property price adjustment systems is presented in subsequent volumes.

Table V. Apparent Specific Gravity Test Results for Limestone and Natural Sand Coarse and Fine Aggregates

Apparent Specific Gravity Results			
Aggregate	Test No.	Percent Absorption	Apparent Specific Gravity
Coarse Limestone			
	1	0.803	2.692
	2	0.696	2.693
	3	0.686	2.693
	Average	0.728	2.693
	[a]Std. Dev.	0.0649	0.0005
Fine Limestone			
	1	1.317	2.674
	2	1.216	2.683
	3	1.174	2.660
	[b]Average	1.236	2.673
	Std. Dev.	0.0735	0.0116
Fine Natural Sand			
	1	1.255	2.726
	2	1.194	2.721
	3	1.235	2.716
	[b]Average	1.228	2.721
	Std. Dev.	0.0311	0.0050

[a] The single operator precision in ASTM C-127 for coarse aggregate is 0.150 for absorption and 0.007 for the apparent specific gravity standard deviation.

[b] The single operator precision in ASTM C-128 for fine aggregate is ±0.300 as the limit between a single test and the average for absorption, and ±0.020 as the limit between a single test and the average specific gravity.

where:

MTSG = maximum theoretical specific gravity,
P1,P2,P3 = percent by weight of aggregate,
G1,G2,G3 = apparent specific gravity of aggregate,
Pb = percent by weight of bitumen,
Gb = specific gravity of bitumen.

Asphalt Concrete Mixing Procedure

Laboratory mixing procedures followed those outlined in Section 2 of the ERLPM. The laboratory procedures for mixing in the FAA Eastern Region are the same as those outlined in the Asphalt Institute's (MS-2) publication. Aggregates were first dried to constant weight at 230°F and sieved into the desired size fractions. Five specimens were prepared for each of the 5 combinations of aggregate and asphalt content.

The mixing temperature, as described in both the ERLPM and the Asphalt Institute's (MS-2) publication, is determined as that temperature producing a kinematic viscosity of 170 +/- 20 centistokes. From the asphalt viscosity-temperature curve in Figure 1, the mixing temperature was determined to be between 297°F and 307°F. The mixing procedure was conducted as follows.

Aggregate specimens were blended by hand and heated overnight to 350°F, 50°F above the mixing temperature described above. The asphalt cement was heated at least 45 minutes prior to mixing to the mix temperature of 297-307°F in covered containers.

The heated mixing bowl was then charged with heated aggregate, and dry-mixed leaving a crater in the center. The required amount of asphalt cement was added until a sample was achieved with the desired asphalt content by total weight. The temperature of the mixture was monitored to assure the investigators that it was within the limits specified for mixing. The specimen was then mixed mechanically for 30 seconds, the bowl was then removed from the mixer and the material was mixed by hand to assure that all aggregate particles on the bottom of the bowl were coated with asphalt cement. The sample was then mixed mechanically for an additional 30 seconds and then thoroughly hand-mixed.

Maximum Specific Gravity Testing by Solvent Immersion and ASTM D-2041

The following laboratory procedure was designed to determine the maximum specific gravity of the asphalt concrete mixture by the ASTM D-2041 and solvent immersion methods. This procedure follows the method given in Appendix D of the ERLPM for determination of maximum specific gravity by solvent immersion. The ASTM D-2041 procedure was followed for the maximum specific gravity determination using the large (Type D) plastic pycnometer. The following calibration procedure was used for each of the 5 asphalt contents and for all 5 replicates.

CHAPTER III

EXPERIMENTAL PROCEDURES

This chapter describes experimental procedures developed to determine maximum specific gravity by the individual constituents, the solvent immersion, and the ASTM D-2041 methods. References are made to standard ASTM testing procedures wherever applicable. Descriptions of the preparation of hot-mixed bituminous material, maximum theoretical specific gravity analysis by individual constituents, and testing procedures by solvent immersion and ASTM D-2041 (Type D) pycnometer are also presented.

Maximum Theoretical Specific Gravity by Individual Constituents

The maximum theoretical specific gravity calculated from the specific gravities of the individual constituents can be determined mathematically for any desired mixture of asphalt and aggregate. The procedure involves separately testing the various components of the mix, i.e., asphalt cement, coarse aggregate, fine aggregate, and mineral filler. Then, the resulting apparent specific gravity values of the individual constituents are entered as input variables into an equation according to their percentage by weight of the total mix. The resulting value is the maximum theoretical specific gravity possible for the particular combination of material used in the asphalt concrete mixture.

Testing was conducted on the coarse limestone aggregate in accordance with ASTM C-127, and the specific gravity of the fine aggregate limestone and natural sand were determined using ASTM C-128 procedures. The specific gravity of the asphalt cement was determined by the asphalt supplier. Testing was performed on the aggregate until the requirements for precision and repeatability listed in ASTM procedures were met. As required by the ERLPM, a minimum of 3 tests were conducted to obtain an average value to be used in individual constituents calculations. Table V lists the specific gravities of the natural sand and limestone aggregates tested, along with the percent water absorption, and the ASTM requirements for repeatability and precision.

Using the average apparent specific gravities of the aggregates, the maximum theoretical specific gravities were calculated for the 5 asphalt contents mentioned in the previous chapter using the following formula, (calculations are given in Appendix A):

$$MTSG = \frac{P1 + P2 + P3 + Pb}{\dfrac{P1}{G1} + \dfrac{P2}{G2} + \dfrac{P3}{G3} + \dfrac{Pb}{Gb}}$$

The final analysis involved a one-way analysis of variance to determine whether the differences between maximum specific gravity determined by solvent immersion or ASTM D-2041 and individual constituents varied with changes in asphalt content. The procedure used an F-test to test the null hypothesis that asphalt content does not affect the difference between either maximum specific gravity determination (solvent immersion or ASTM D-2041) and the maximum theoretical specific gravity obtained by individual constituents.

Steps Taken to Limit Sampling and Testing Variability

Efforts were made to eliminate or minimize sampling and testing variability which might affect the test results. Over 20 specimens were produced and tested as trial runs to familiarize the researcher with the equipment and to enable him to develop and modify the testing procedure. All testing was performed by one researcher to eliminate variation associated with more than one operator. The limestone and natural sand aggregate were sieved into the proper gradation with more than enough material in each sieve size to complete all phases of the experiment. Materials were thoroughly blended within each sieve size to assure uniform aggregate quality throughout the experiment. Distilled water and a single supplier of trichloroethylene were used to ensure constant specific gravity of the testing media. Random sampling was used to reduce sampling bias.

Method of Analysis

The primary purpose of the research was to provide statistical results for the comparison of maximum specific gravity measured by the following techniques: individual constituents, solvent immersion, and ASTM D-2041 procedures.

Comparison of Results Obtained from Solvent Immersion and ASTM D-2041 Techniques

The analysis of the maximum specific gravity results determined by solvent immersion and ASTM D-2041 was performed using a sample t-test (TTEST) available in SAS (5). The analysis first involved a comparison of the variances using an F-test to test the null hypothesis that the variance of the solvent immersion and ASTM D-2041 test procedure were equal at each asphalt content. Then, using the t-test, the means of the 2 procedures were compared to determine if a difference existed between results obtained from the solvent immersion and ASTM D-2041 procedures at each asphalt content.

Individual Constituents Comparisons With Solvent Immersion and ASTM D-2041 Procedures

The results obtained experimentally for maximum specific gravity by solvent immersion and ASTM D-2041 were subtracted from the constant maximum theoretical specific gravity determined by individual constituents at each asphalt content. Using SAS (5) procedure UNIVARIATE, a t-test was conducted to test the null hypothesis that the mean of the differences was zero. A mean difference of zero implies no difference in the 2 methods.

Table IV. Sample Sizes for Each Specimen

Sample Sizes for 7980 gram Specimen	
ASTM D-2041 procedure	6000 grams
Solvent Immersion	1250 grams
10% Waste and Spillage	730 grams
Total	7980 grams

minimum sample sizes required by the ASTM standards for the Rochester JMF gradation were 3000 grams for the limestone coarse aggregate, 1000 grams for the limestone fine aggregate, and 1000 grams for the natural sand fine aggregate.

The solvent immersion test procedure is outlined in the ERLPM (4) with a recommended sample size of 1200 grams. After discussions with FAA personnel, it was decided to use a 1250 gram sample, approximately the size of 1 standard Marshall test specimen.

Sample size requirements given in the ASTM D-2041 procedure are 2000 grams for gradations with 3/4 inch maximum size particles. The literature received with the test equipment (9) suggested that a 6000 gram sample be used with the large (Type D) plastic pycnometer, and this is a common size for specimens tested in field laboratories. Since large samples provide higher accuracy, 6000 gram samples were used.

To determine the number of replicates to produce, power calculations were made to detect a specified amount of difference in maximum specific gravity results between asphalt contents. For the 5 asphalt contents used in this analysis, and a maximum variance of 0.004 allowed by the ASTM D-2041 procedure for repeatability, the power calculations (10) generated a noncentrality parameter for an F-distribution to detect a difference of at least 0.011 between 2 of the means, with an alpha = 0.05 level of significance.

Considering this, there would be a 55.1% chance with 3 replicates, a 75.0% chance with 4, an 88.2% chance with 5, and a 94.3% chance with 6 replicates of detecting a difference of 0.011 between the 2 means. It was decided to use 5 replicates since the time and expense involved outweighted the additional statistical significance gained using the sixth replicate.

Testing Procedure

Tests to determine the apparent specific gravity of the limestone and natural sand were conducted in accordance with ASTM C-127 and C-128. The maximum theoretical specific gravity calculated using individual constituents requires that the apparent specific gravity used in the calculations be the average of 3 test values (4).

The mix design procedures followed in the preparation of bituminous material for the ASTM D-2041 and solvent immersion tests are outlined in the ERLPM and are the same as those outlined in developing a job mix formula in the Asphalt Institute's Manual Series No. 2 (MS-2) "Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types" publication (11). At each of the 5 asphalt contents for the 5 replicates tested a 7980 gram sample was produced. This sample was composed of the quantities listed in Table IV. The solvent immersion and ASTM D-2041 tests were then performed before the material cooled. A detailed description of the mixing and testing procedure is given in the following chapter.

Table II. Rochester-Monroe County Airport, Runway 10-28, Job Mix Formula Gradation

Gradation	
Sieve Size	Percent by Weight Passing Sieve
3/4"	100.0
1/2"	98.6
3/8"	84.6
#4	66.5
#8	55.0
#16	42.0
#30	31.0
#50	20.0
#100	8.5
#200	3.8

Table III. Asphalt Content Results from Three Runway Paving Projects (12).

Asphalt Content Results					
Data Source	Mean (%)		Standard Dev. (%)	Range	
	JMF	Actual		Min.	Max.
NAFEC	4.9	4.83	0.24	4.3	5.9
BWI	5.5	5.64	0.07	5.5	5.8
Rochester	6.2	6.05	0.27	5.3	6.7

specimens required for the maximum theoretical specific gravity by individual constituents determination, and sample sizes for the solvent immersion and the ASTM D-2041 (Type D) large pycnometer maximum specific gravity tests also had to be determined.

The laboratory testing procedures involved conducting the related tests needed to determine maximum theoretical specific gravity by individual constituents and developing procedures required to prepare samples of bituminous material to determine maximum specific gravity by solvent immersion and ASTM D-2041.

Gradation and Asphalt Content Determination

A gradation was developed for use on the Rochester-Monroe County Runway 10-28 project, listed in Reference (12), for the same material used in this laboratory analysis and the laboratory phase of the Marshall property acceptance research (6). The Rochester JMF gradation is listed in Tabel II.

The optimum asphalt content for the gradation was determined to be 6.3% in the Marshall property laboratory analysis (6). The Rochester JMF gradation and the 6.3% optimum asphalt content determined for the material were used in this laboratory investigation.

To determine the range of asphalt contents to use, comparisons were made among the standard FAA Eastern Region Specification, various state bituminous surface course specifications for hot mix plant construction, and results from the projects studied in the field data analysis discussed in Reference (12). Each of the specifications required the bitumen content to be between 5.0% and 7.5% of the total mix. The average asphalt content, standard deviation, and range of values from the 3 construction projects studied in the field analysis (12) are given in Table III.

A standard deviation of 0.27 was the largest observed on any project. Using the field data as a guide for this experiment, 5 asphalt contents were selected, one at optimum for the material tested, one each at 0.3% above and below optimum, and at 0.6% above and below optimum. The 0.3% is roughly equal to the largest standard deviation observed from the field data. Plus or minus 0.6% is therefore equal to 2 standard deviations away from optimum. This represents roughly a 95% level of confidence of spanning the range of values experienced under actual field conditions if asphalt contents are distributed normally about the optimum asphalt content.

Sample Size Determination

Sample size requirements to determine apparent specific gravity of coarse aggregate and fine aggregate are given in ASTM procedures C-127 "Specific Gravity and Absorption of Coarse Aggregate" (7), and C-128 "Specific Gravity and Absorption of Fine Aggregate" (8). The quantity of material needed to perform the test accurately is based on the maximum size fraction of the aggregate used in the gradation. The

Table I. Characteristics of Asphalt Cement as Determined by West Bank Oil, Inc.

AC-20 Asphalt Cement	
Test Characteristic	Test Value
Penetration value @ 77°F	79
Absolute Viscosity @ 140°F	1971 poises
Kinematic Viscosity @ 275°F	376 Centistokes
Specific Gravity	1.024

CHAPTER II

RESEARCH PROCEDURE

At the commencement of this study, the FAA Eastern Region employed a procedure for adjusting the maximum specific gravity determined by the ASTM D-2041 or solvent immersion method during production to an equivalent maximum theoretical specific gravity by the individual constituents method. This adjusted maximum specific gravity was used with the bulk specific gravity in air voids calculations to determine substantial compliance with specification tolerence limits during production. This portion of the research was designed to investigate the different maximum specific gravity results obtained using the individual constituents method, the ASTM D-2041 method and the solvent immersion method, and to determine whether these differences vary with the asphalt content of the paving mixture.

Description of Materials Tested

The aggregate and asphalt cement used in this research were also used in the laboratory phase of the analysis of Marshall properties (6), and are representative of the type used in the FAA Eastern Region. The asphalt cement was obtained from West Bank Oil, Inc., Pennsauken, New Jersey. It was graded as AC-20 with the specifications listed in Table I, as determined by West Bank Oil.

The limestone aggregate used was received from General Crushed Stone Company, Honeoye Falls, New York. Natural sand from Baugham Materials and Concrete, Inc., in West Bloomfield, New York was also used. Natural sand is added to the mix to increase the workability and facilitate field compaction. The FAA Eastern Region allows a maximum of 20% by weight.

The coarse and fine aggregate passed all requirements listed in the New York State Specification. These include, for coarse aggregate: Los Angeles Abrasion, Sodium Sulfate and Magnesium Sulfate Soundness, and tests for flat and elongated and crushed pieces; for fine aggregate: Plastic Index and Liquid Limit requirements. These tests on the aggregate were conducted by General Crushed Stone for use on the Rochester-Monroe County Airport Project discussed in Reference (12). The specific gravities were determined by the researchers and are given in subsequent sections.

Experimental Design

The preliminary investigation involved selecting an aggregate gradation, defining the optimum asphalt content, and the range of asphalt contents to be tested. The sample sizes of standard test

2. A comparison of the maximum theoretical specific gravity obtained by individual constituents and the solvent immersion maximum specific gravity with variations in asphalt content.

3. A comparison of the maximum theoretical specific gravity obtained by individual constituents and the ASTM D-2041 maximum specific gravity with variations in asphalt content.

At the time of this study, the Eastern Region Laboratory Procedures Manual allowed the use of either ASTM D-2041 or solvent immersion for determining maximum specific gravity. The results of this study can be used to investigate the relationships among the maximum specific gravity determined by the ASTM D-2041, solvent immersion, and individual constituents methods. These results may be used to evaluate methods for air voids determination.

During production, the maximum specific gravity used in air voids calculations for acceptance purposes by the FAA Eastern Region was determined by 1 of 2 methods. The first, and most commonly used method, involved submerging a loose asphalt mixture in water and removing the entrapped air with a partial vacuum. This procedure is described in ASTM D-2041 "Maximum Specific Gravity of Bituminous Paving Mixtures" (3). The second method removes the entrapped air from a loose specimen by dissolving the asphalt in a solvent. This breaks up the sample and replaces the air voids with solvent allowing the volume of the asphalt cement and aggregate to be determined. This method was referred to by the FAA Eastern Region as the solvent immersion method.

Obviously, the 3 methods, due to differences in testng procedures, may yield differing results. This, in turn, can create differences in calculated air voids values.

Basis for Study

The optimum asphalt content accepted by the FAA Eastern Region was determined as that asphalt content producing air voids values which are at the midpoint of the specification limit. Using the maximum theoretical specific gravity of the individual constituents method, the asphalt content producing a 3.5 percent air voids value, the midpoint of a 2.8 - 4.2 percent design specification, was designated as optimum. At that asphalt content, stability and flow were checked for compliance with job mix formula specification limits.

Three tests were then conducted using either the ASTM D-2041 or the solvent immersion test method on material produced at the optimum asphalt content to determine maximum specific gravity. These values were averaged, and the difference between the average and the individual constituents maximum theoretical value became a correction factor for use in air voids calculations. Either the ASTM D-2041 or the solvent immersion method was used to determine maximum specific gravity during production for use in air voids anlysis.

This correction factor recognized that differences exist in the maximum specific gravity determined by individual constituents, ASTM D-2041, and solvent immersion. The system did not consider changes that might occur between maximum specific gravity determined by the 3 methods, and the resulting air voids values, when material is produced at asphalt contents which differ from optimum.

Research Objectives

The purpose of this study was to compare through laboratory experimentation the maximum specific gravity determination methods used in air voids anlysis. This area of the research addressed the following tasks.

1. A comparative analysis of the maximum specific gravity determined using ASTM D-2041 and solvent immersion with variations in asphalt content.

CHAPTER I

INTRODUCTION

The Federal Aviation Administration (FAA) Eastern Region along with other state and federal engineering agencies has adopted the Marshall method for analyzing the properties of asphalt pavements. These procedures, standardized by the American Society for Testing and Materials (ASTM), establish criteria used to evaluate laboratory designed asphalt concrete and to control plant production and field placement. The 2 principal features of the Marshall method are a density and air voids analysis and a load-deformation test for compacted asphalt paving mixtures.

Using ASTM procedure D-2726, "Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens" (1), the density is determined by multiplying the bulk specific gravity by 62.4 lb/cu ft. The air voids represent the percentage of the total volume that is occupied by air spaces within the compacted specimen. This is determined mathematically using the bulk specific gravity and the maximum specific gravity of the paving mixture.

The percent air voids is a volumetric quantity, and therefore can not be weighed directly. For design and analysis, air voids values are determined by comparing the specific gravity of a compacted sample with air voids present, known as the bulk specific gravity, with the maximum specific gravity of the material, i.e., with no air voids present. The percent air voids in the compacted specimen is determined by subtracting the ratio of bulk specific gravity to maximum specific gravity from 1. Although there is only 1 method for determining the bulk specific gravity, ASTM D-2726, there were 3 methods recognized by the FAA Eastern Region for determining the maximum voidless specific gravity.

During the development stages of the job mix formula (JMF), which is the desired combination of asphalt cement and aggregate to be used during production, the FAA Eastern Region has adopted a method called the maximum theoretical specific gravity by individual constituents for maximum specific gravity determination in air voids calculations. The procedure involves individually determining the specific gravities of the coarse aggregate, fine aggregate, mineral filler, and asphalt cement. The specific gravities of the individual constituents are then combined mathematically according to their percent by weight of the total mixture. The resulting value is the maximum specific gravity for a theoretical sample of material. Obviously, by varying the particular amounts of each component, the maximum theoretical specific gravity can be determined for any asphalt content.

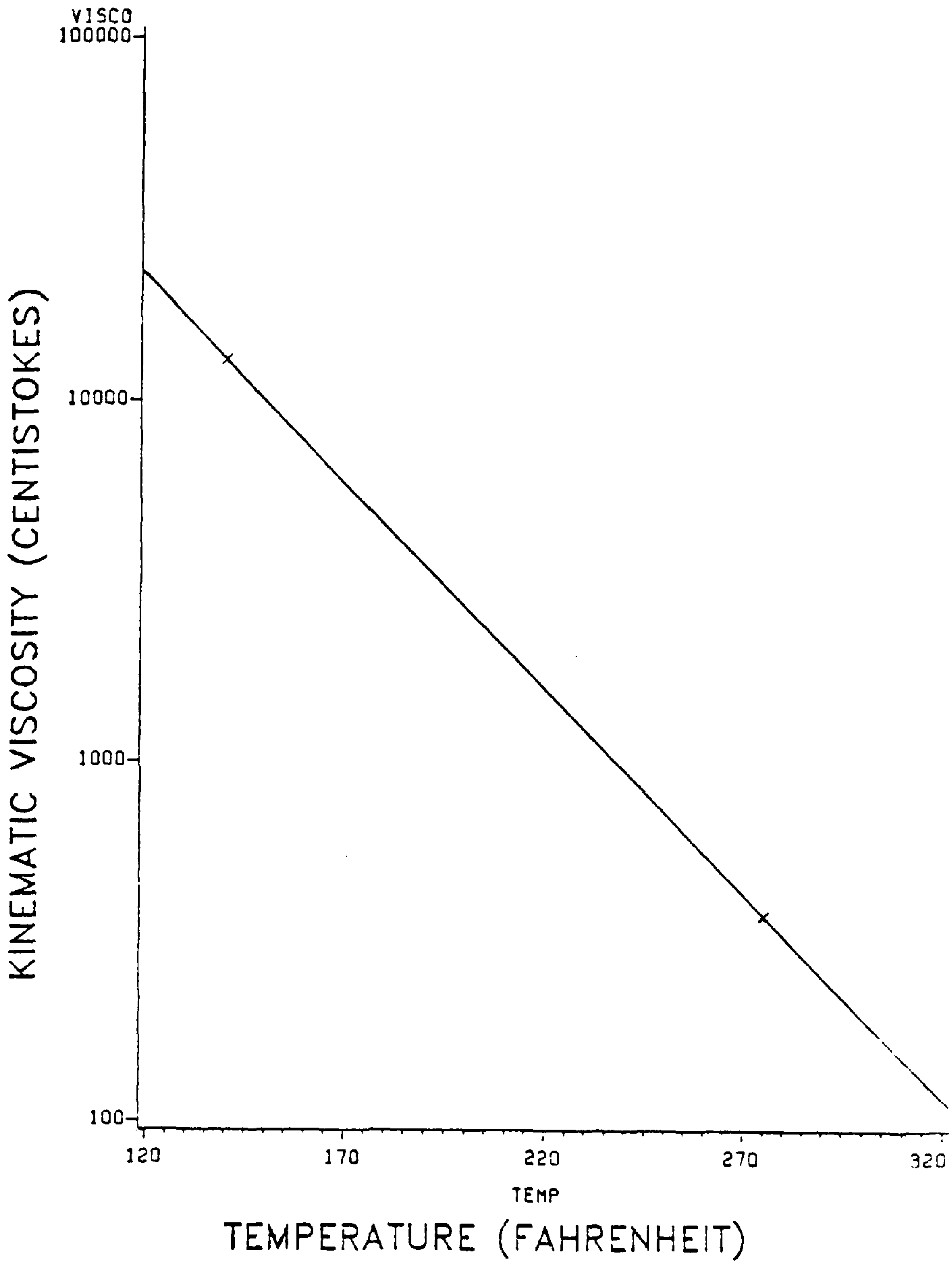


Figure 1. AC-20 Asphalt Cement Viscosity Curve

Calibration of Test Equipment

Calibration of a pycnometer, like the type shown in Figure 2, was performed before testing to determine the mass of water required to fill the pycnometer over a range of temperatures. The main purpose of the calibration procedure was to obtain a calibration curve of water weight versus water temperature for use in maximum specific gravity calculations. The domed lid of the pycnometer was latched and filled with distilled water leavng about 2 inches of air space at the top. A vacuum of at least 28 psi was then applied for approximately 10 minutes. Further release of the air bubbles was facilitated by dropping one end and then the other of the pycnometer from about 1/2-inch height.

The vacuum was removed and water carefully added until the level was about half-way up the neck of the pycnometer. The vented stopper was inserted enough to seat the stopper and all excess water was wiped from the outside of the pycnometer. The full pycnometer was weighed to the nearest gram on a triple beam balance and the temperature of the water was recorded. This procedure was repeated over a temperature range of about 70°F to 150°F until a smooth calibration curve was produced. The calibration curve for the pycnometer used during the experiment is shown in Figure 3.

A sketch of a typical 1000 ml. solvent immersion flask is shown in Figure 4. Calibration of the solvent immersion flask was performed before mixing and testing of each specimen. The procedure involved determining the weight of the flask empty (to within 0.1 grams) and then filled to the calibration mark with trichloroethylene at 77°F.

Testing Procedure

The following procedure was developed from the guidelines in the FAA ERLPM, ASTM standards, and manufacturer's literature. The procedure was also modified as a result of over 20 practice tests. Material was mixed as described above and its maximum specific gravity was then determined using the solvent immersion and ASTM D-2041 (Type D) methods. The data sheet used to record the test results for determining maximum specific gravity by solvent immersion and ASTM D-2041 is shown in Figure 5.

Approximately 1250 grams of the material from the middle of the mixing bowl were added directly to the 1000 ml. flask. Trichloroethylene was added slowly until the material was covered by approximately 3/4-inch of solvent. The top was fitted and the flask was shaken, agitated, and rolled until all air bubbles had been removed. The flask was then filled to the calibration mark with trichloroethylene and placed in a circulating water bath to bring the temperature to 77°F. After 2 hours in the water bath, the flask was filled to the calibration mark with trichloroethylene. The temperature was checked until 77°F was attained and then the flask was weighed. A sample calculation for determining the maximum specific gravity by solvent immersion is presented in Appendix B.

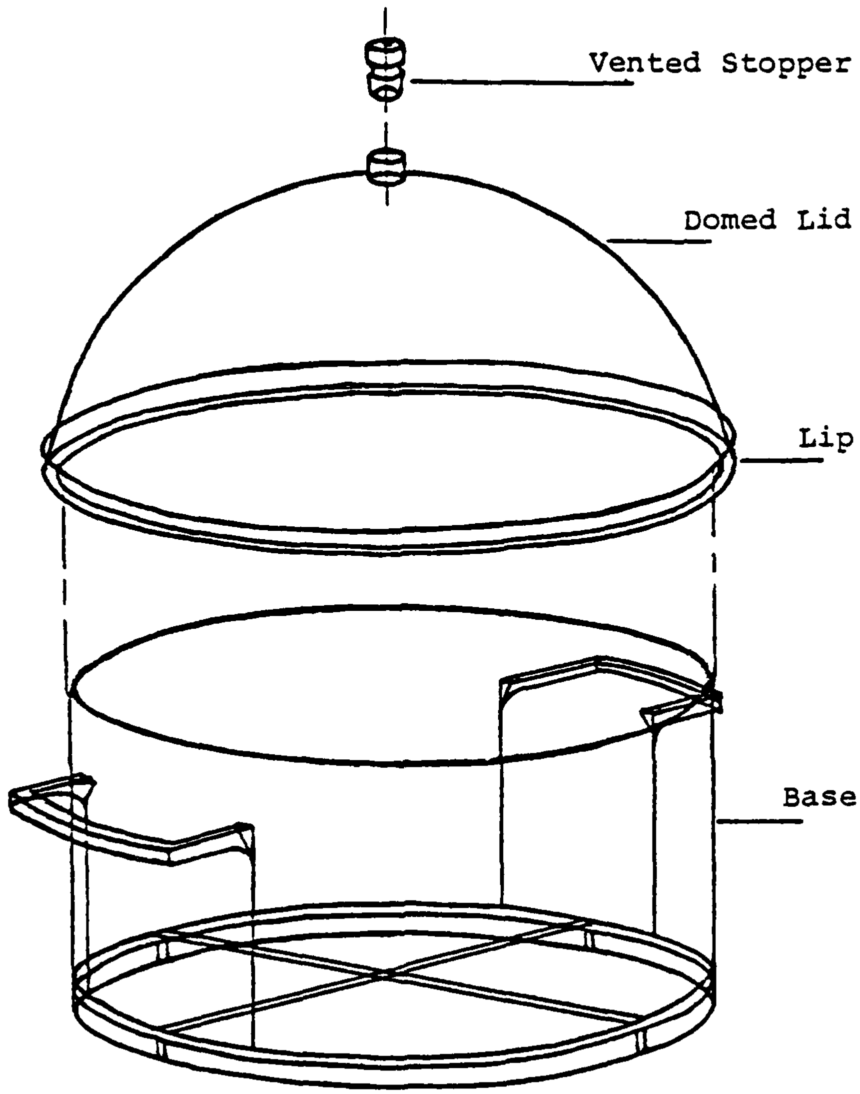


Figure 2. 10,000 ml. (Type D) Plastic Pycnometer

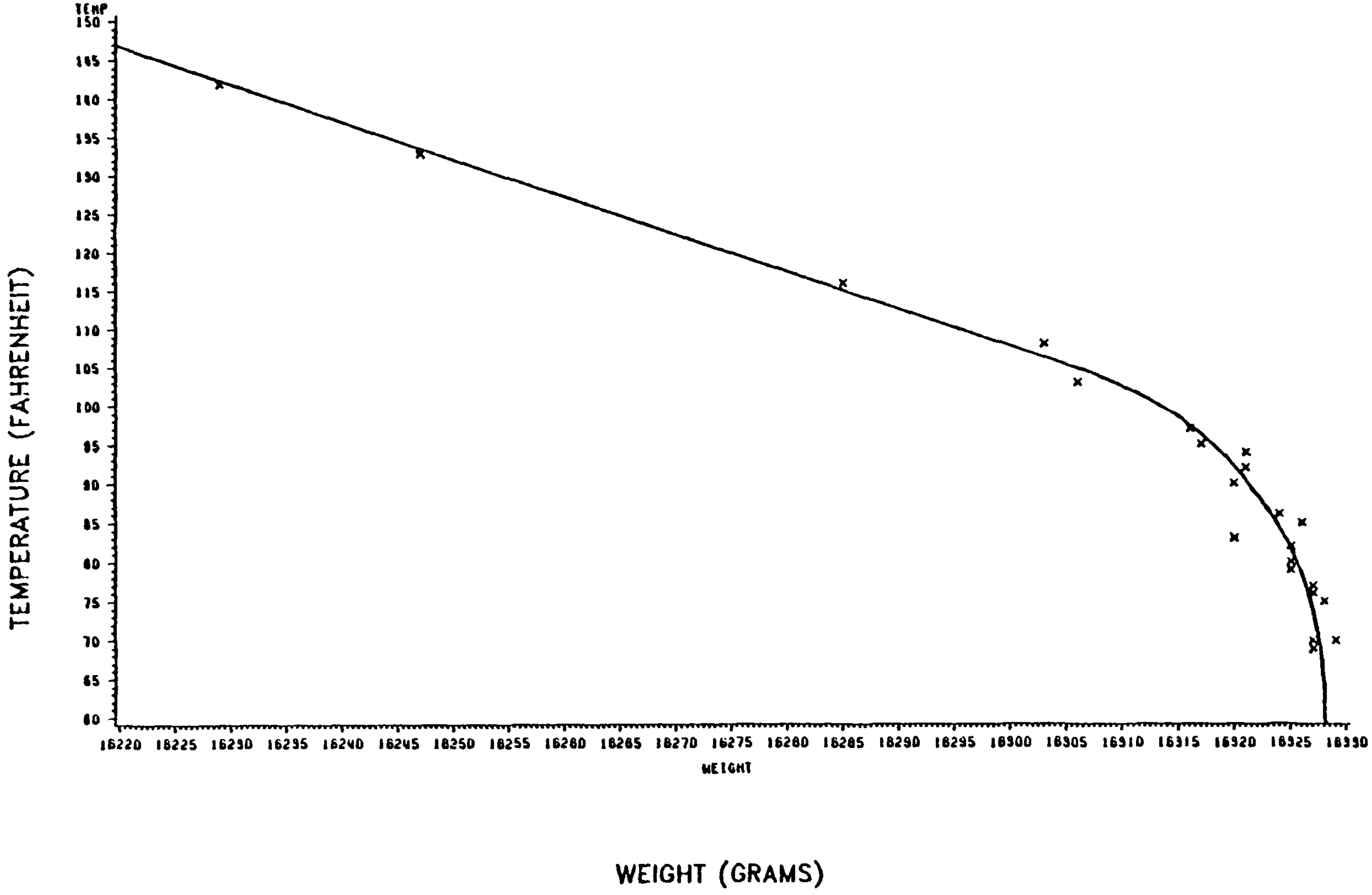


Figure 3. Calibration Curve for Pycnometer

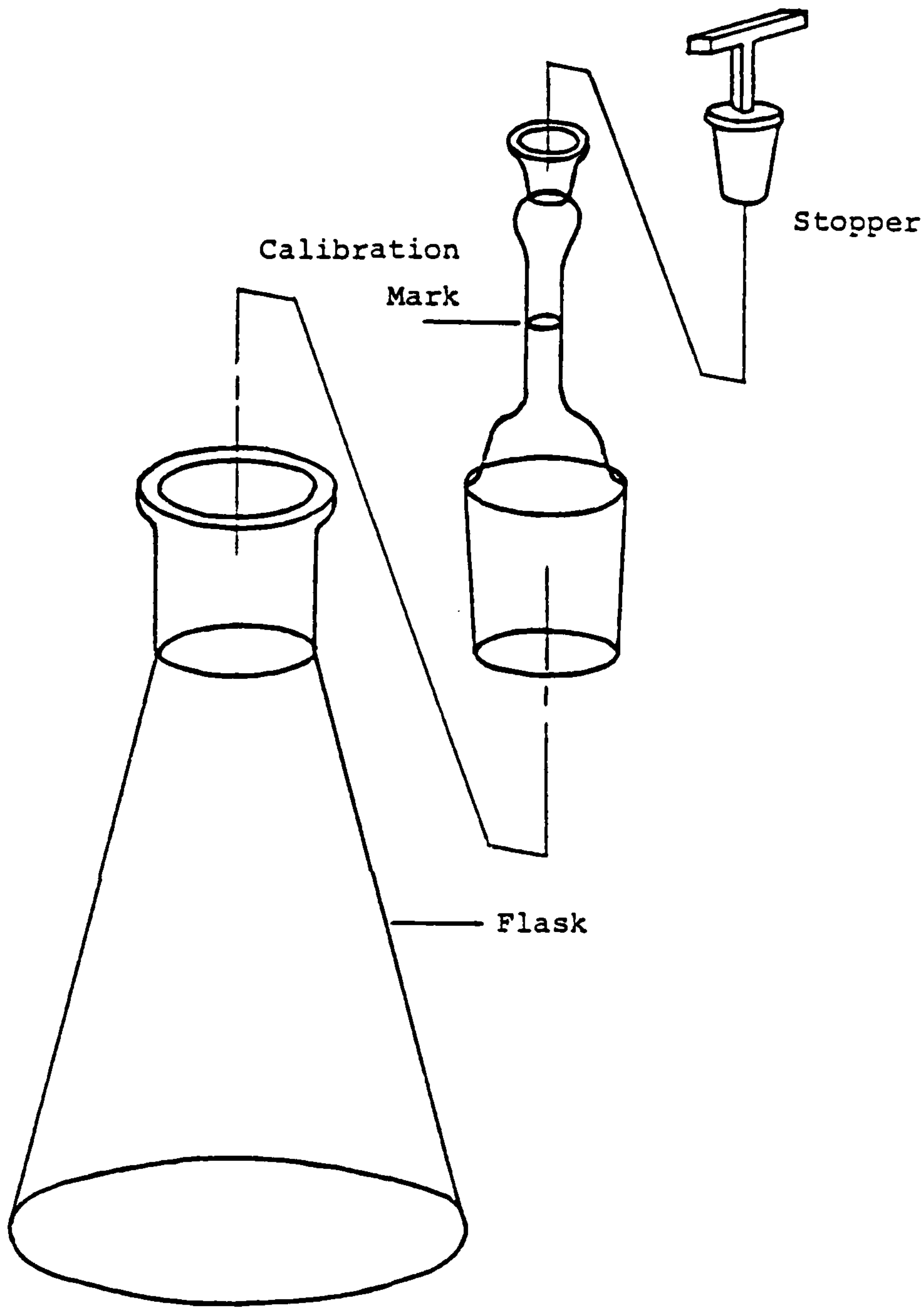


Figure 4. Typical 1000 ml. Solvent Immersion Flask

DATA SHEET FOR MAXIMUM SPECIFIC GRAVITY BY
TYPE D PYCNOMETER AND SOLVENT IMERSION

REPLICATE ______ DATE ______					
ASHPAHLT CONTENT					
TYPE D M.S.G.					
TARE AND MIX					
TARE					
PYC + MIX + WATER					
TEMP					
SI M.S.G.					
FLASK					
FLASK + SOLV.					
FLASK + MIX					
FLASK + MIX + SOLV.					
COMMENTS:					

Figure 5. Maximum Specific Gravity Laboratory Test Data Sheet

A 6000 gram sample of material was weighed for testing with the large pycnometer used in the ASTM D-2041 (Type D) procedure. After 2 inches of distilled water were poured into the bottom of the pycnometer and the 6000 grams of material were added, the domed lid was latched. More distilled water was added until about 2 inches of air space was left at the top of the pycnometer. The stopper was inserted and the pycnometer agitated to prevent lumping of the material. The stopper was removed and a vacuum of at least 28 psi was applied for 10 minutes. While under vacuum, every 2 minutes the pycnometer was agitated to aid in the removal of air bubbles by dropping one end and then the other from a height of about 1/2-inch. After 10 minutes, the vacuum was removed and the pycnometer was carefully filled with water. The stopper was then inserted and excess water was wiped from the outside. The pycnometer with the asphalt mixture and water was then weighed on a triple beam balance to the nearest gram and the temperature of the water was recorded. A sample calculation to determine maximum specific gravity by ASTM D-2041 is shown in Appendix B.

CHAPTER IV

ANALYSIS OF EXPERIMENTAL RESULTS

In this chapter, the computation of the maximum theoretical specific gravity determined by individual constituents and the maximum specific gravity results determined experimentally by the solvent immersion method and the ASTM D-2041 method are presented. Three tests were conducted using ASTM procedures C-127 and C-128 to determine the apparent specific gravities of the limestone and natural sand aggregates for the calculation of maximum theoretical specific gravity by the individual constituents method. Five replicates were made, each consisting of 5 asphalt contents, to determine maximum specific gravity by the solvent immersion and ASTM D-2041 methods. Experimental data used in the calculations are listed in Appendix C.

Three comparative analyses were conducted using the Statistical Analysis System (SAS) (5). The specific comparisons were between the procedures listed in Table VI.

Experimental Test Results

This section presents the specific gravities from the individual constituents maximum theoretical specific gravity and the solvent immersion and ASTM D-2041 maximum specific gravity results.

Using the apparent specific gravity of the coarse and fine aggregate, shown in Table V in the previous chapter, calculations were made to determine the maximum theoretical specific gravity for each of the 5 asphalt contents. The maximum theoretical specific gravity is calculated only once for each asphalt content. Calculations are presented in Appendix A. The resulting maximum theoretical specific gravity values for the 5 asphalt contents are given in Table VII, and the same values are shown for each replicate for comparison purposes.

Calculations were made to determine maximum specific gravity by the solvent immersion and ASTM D-2041 procedures using the experimental results listed in Appendix C. The results are listed in Table VII for the 5 asphalt contents for each of 5 replicates. The data are also represented in plots of maximum specific gravity versus asphalt content in Figure 6. The resulting means and standard deviations for the test procedures are listed in Table VIII, and are plotted in Figures 7 and 8, respectively, for the 5 asphalt contents.

Figure 6 indicates that a decrease in maximum specific gravity occurs as the asphalt content increases. As expected, a constant volume of material would weigh less if the percentage of a material with lower specific gravity were increased. The specific gravity of asphalt cement is less than that of aggregates. Figure 6 shows that the solvent

Table VI. Maximum Specific Gravity Comparisons

Specific Gravity Comparisons
1. Solvent Immersion versus ASTM D-2041
2. Solvent immersion versus Individual Constituents
3. ASTM D-2041 versus Individual Constituents

Table VII. Experimental Results for Individual Constituents, Solvent Immersion and ASTM D-2041 Procedures

Maximum Specific Gravities				
		Test Method		
Replicate	Asphalt Content	Individual Constituents	Solvent Immersion	ASTM D-2041
1	5.7%	2.461	2.460	2.437
	6.0%	2.450	2.443	2.421
	6.3%	2.439	2.440	2.406
	6.6%	2.428	2.425	2.389
	6.9%	2.418	2.414	2.381
2	5.7%	2.461	2.454	2.430
	6.0%	2.450	2.444	2.422
	6.3%	2.439	2.443	2.405
	6.6%	2.428	2.428	2.388
	6.9%	2.418	2.414	2.384
3	5.7%	2.461	2.461	2.431
	6.0%	2.450	2.444	2.424
	6.3%	2.439	2.437	2.401
	6.6%	2.428	2.430	2.394
	6.9%	2.418	2.412	2.376
4	5.7%	2.461	2.459	2.435
	6.0%	2.450	2.446	2.419
	6.3%	2.439	2.436	2.404
	6.6%	2.428	2.427	2.393
	6.9%	2.418	2.419	2.380
5	5.7%	2.461	2.456	2.438
	6.0%	2.450	2.452	2.416
	6.3%	2.439	2.439	2.409
	6.6%	2.428	2.423	2.391
	6.9%	2.418	2.416	2.377

Table VIII. Mean and Standard Deviation Results for Individual Constituents, Solvent Immersion and ASTM D-2041 Procedures

	Asphalt Content	Test Method: Individual Constituents	Test Method: Solvent Immersion	Test Method: ASTM D-2041
		Maximum Specific Gravity		
5 Replicates	5.7%	2.461	2.458	2.43[illegible]
	6.0%	2.450	2.446	2.420
	6.3%	2.439	2.439	2.405
	6.6%	2.428	2.427	2.391
	6.9%	2.418	2.415	2.380
		Standard Deviation		
5 Replicates	5.7%	*	0.0029	0.0036
	6.0%	*	0.0036	0.0031
	6.3%	*	0.0027	0.0030
	6.6%	*	0.0027	0.0026
	6.9%	*	0.0027	0.0035

* - The individual constituents results were calculated only once

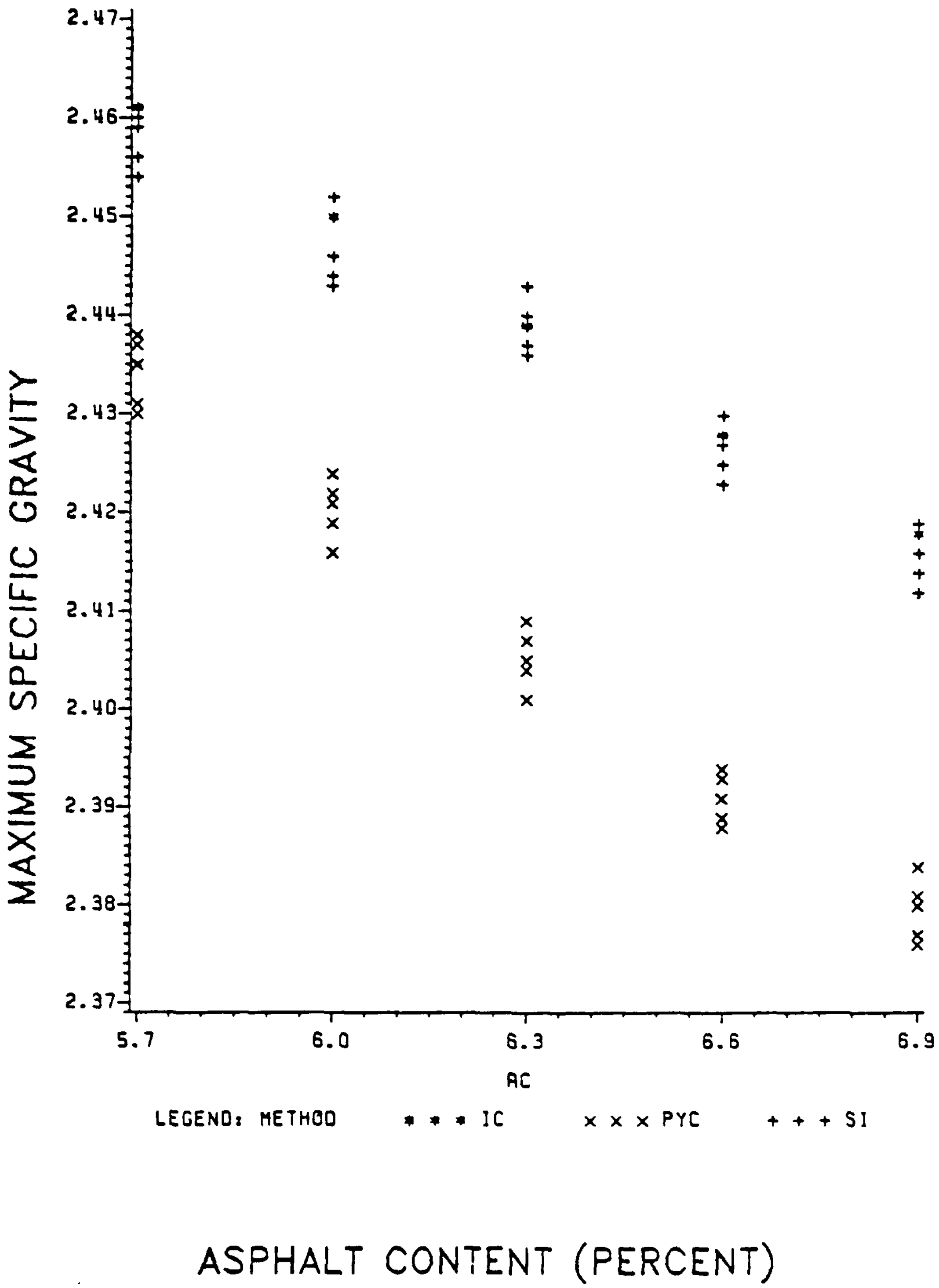


Figure 6. Maximum Specific Gravity Values versus Asphalt Content for all Five Replicates

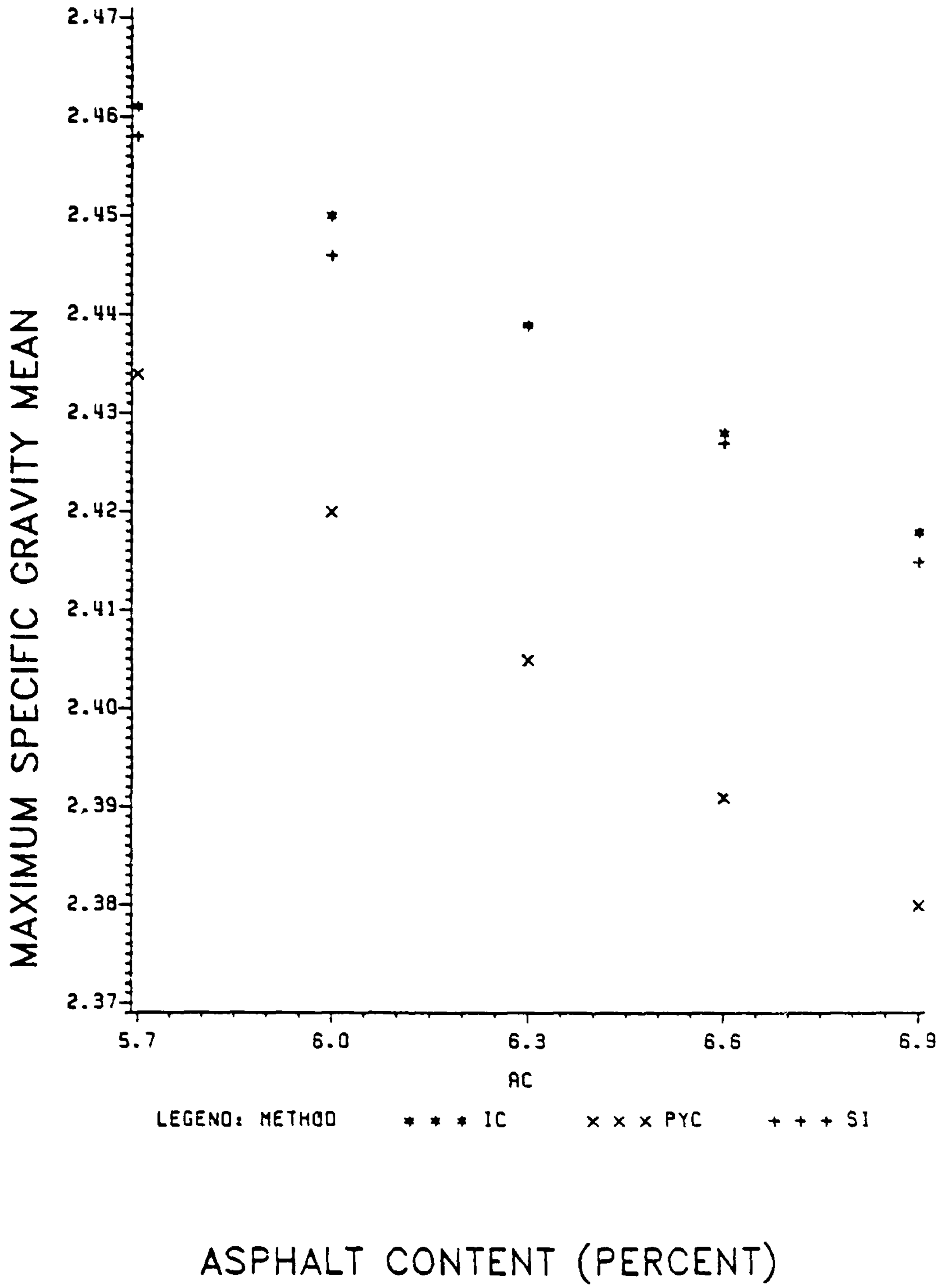


Figure 7. Mean Maximum Specific Gravity Values versus Asphalt Content for all Five Replicates

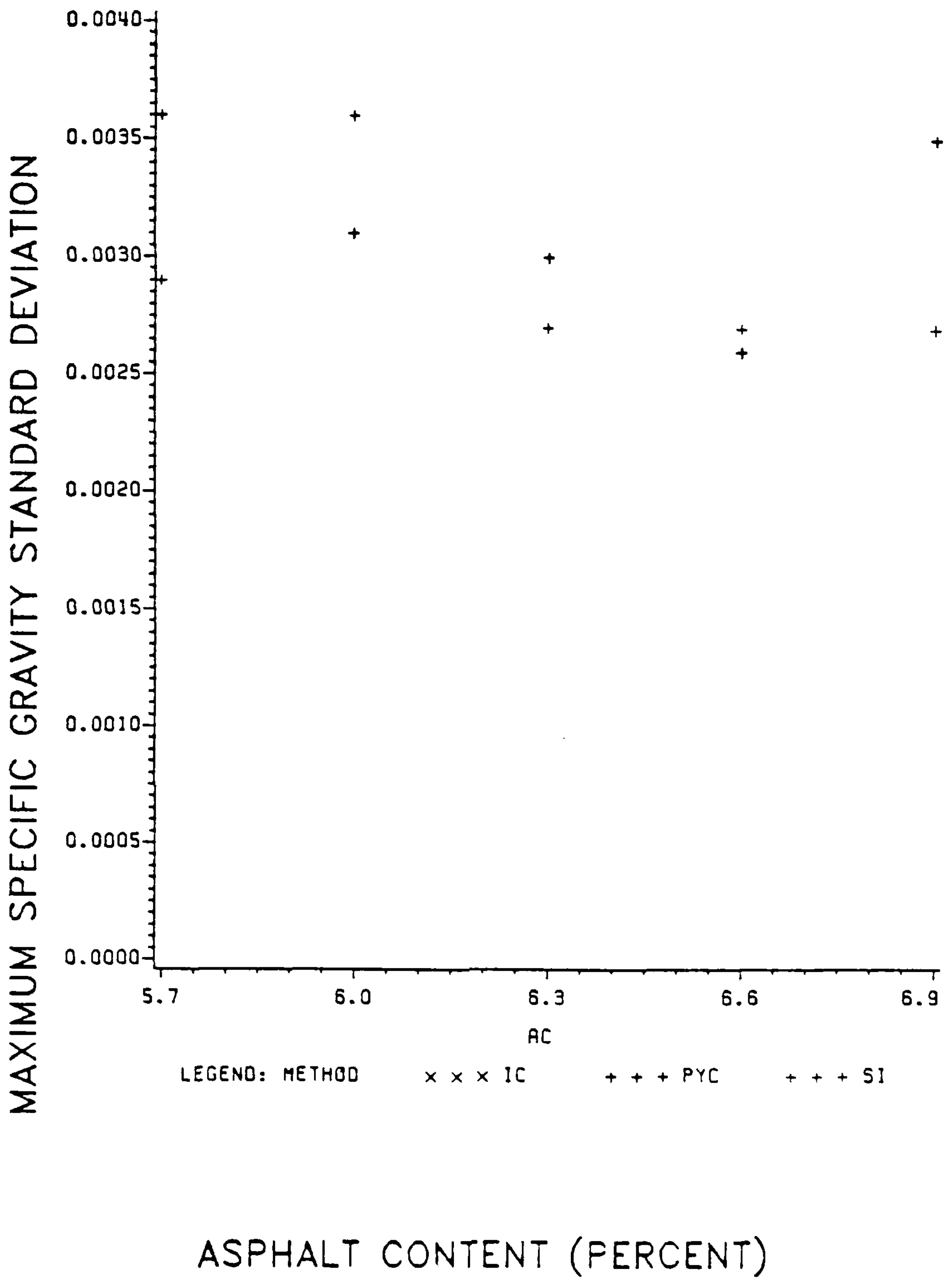


Figure 8. Maximum Specific Gravity Standard Deviation versus Asphalt Content for all Five Replicates

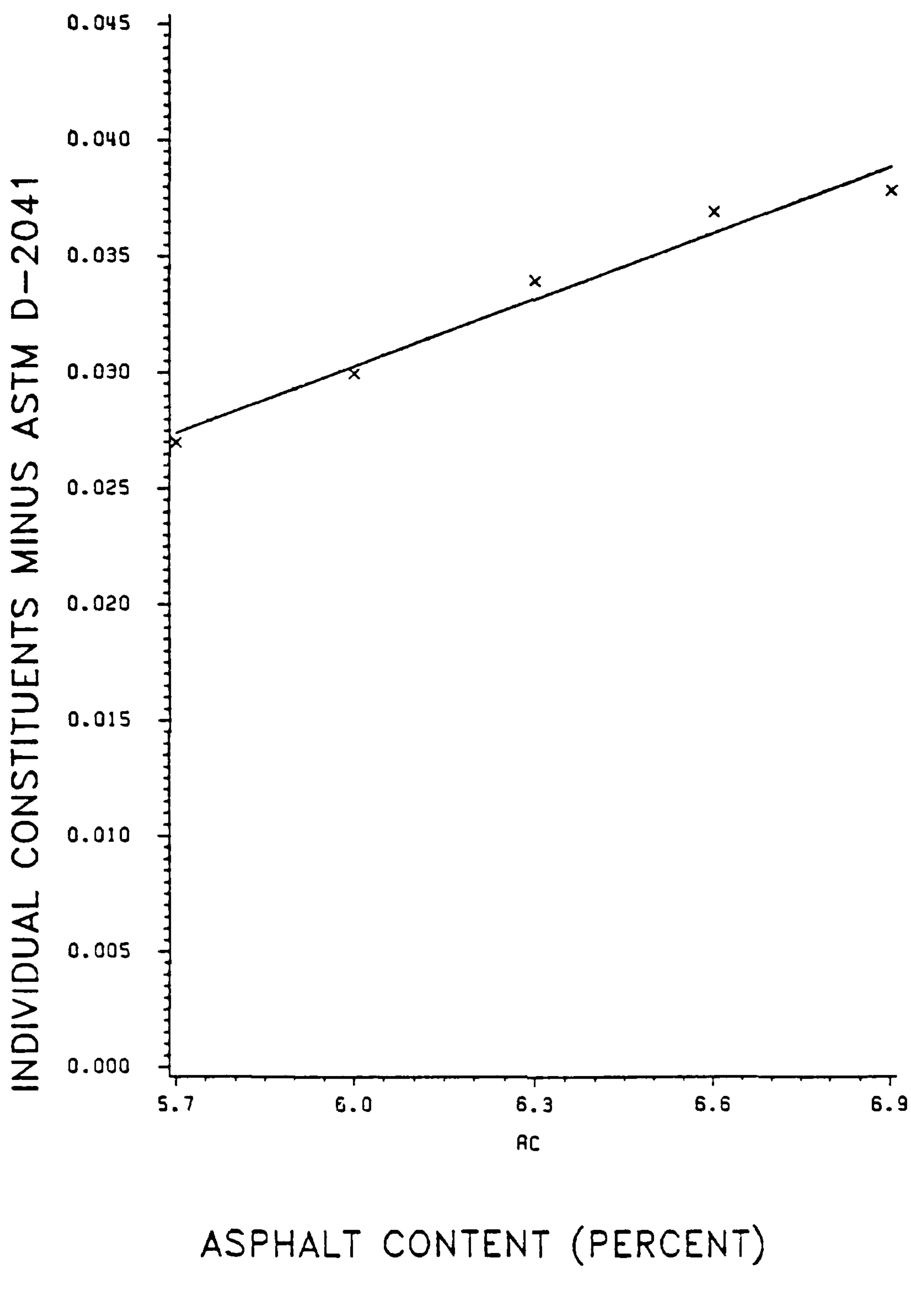


Figure 12. Mean Difference Between ASTM D-2041 and Individual Constituents Results versus Asphalt Content

Table XIV. t-Test for Comparison of ASTM D-2041 and Individual Constituents Results for the Five Asphalt Contents

SAS (5) UNIVARIATE Results		
	Means Difference Analysis	
Asphalt Content	t-Statistic	Prob>|t| [a]
5.7%	12.8158	0.0001
6.0%	21.7038	0.0001
6.3%	24.9177	0.0001
6.6%	32.4511	0.0001
6.9%	26.7545	0.0001

[a] Probability of test values exceeding the absolute t statistic.

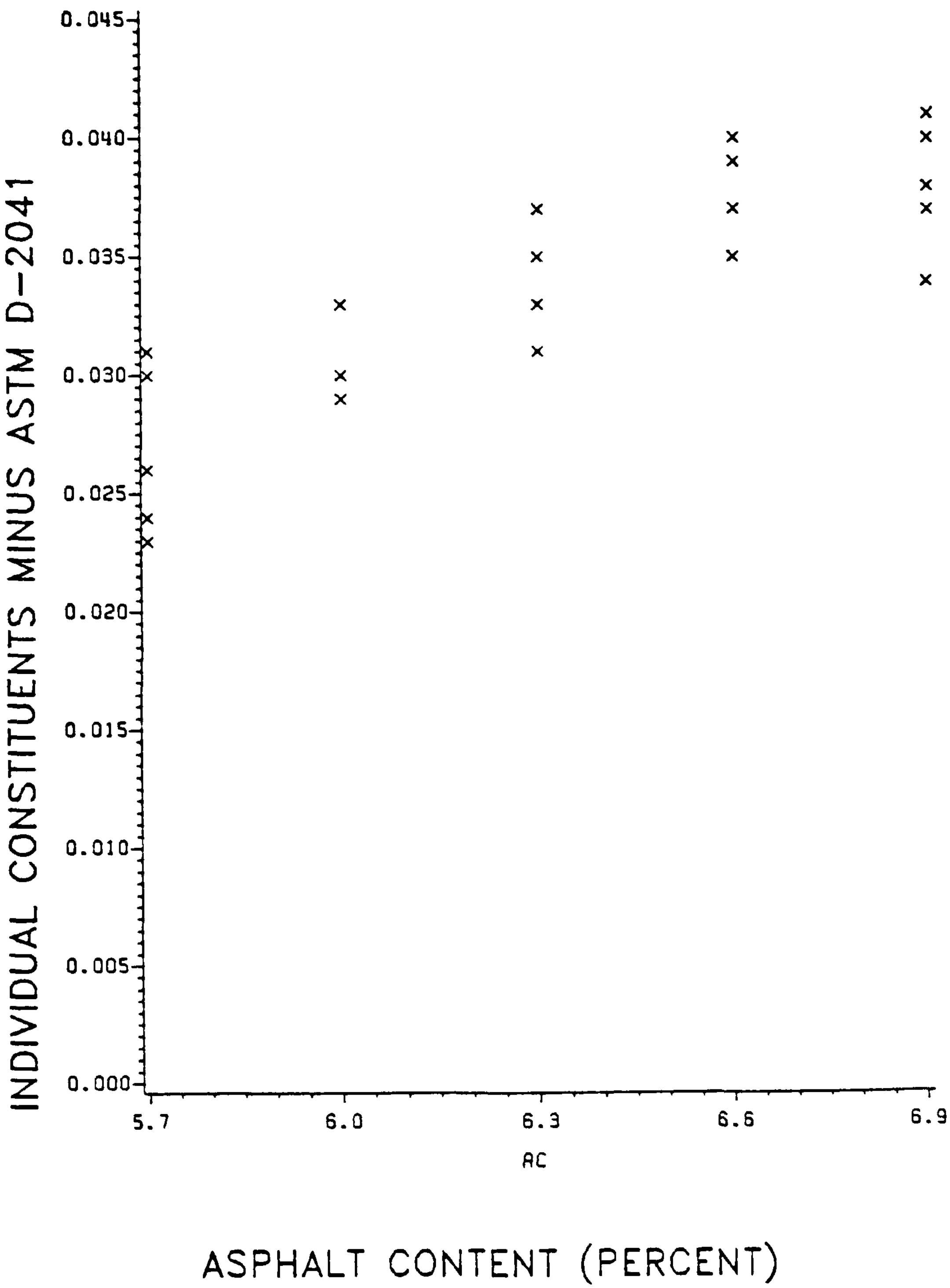


Figure 11. Plot of Differences Between ASTM D-2041 and Individual Constituents Results versus Asphalt Content

Table XIII. Difference Data Between the ASTM D-2041 and the Individual Constituents Values for the Five Asphalt Contents

Individual Constituents minus ASTM D-2041						
	Replicate					
Asphalt Content	1	2	3	4	5	Avg.
5.7%	0.024	0.031	0.030	0.026	0.023	0.027
6.0%	0.029	0.028	0.026	0.031	0.034	0.030
6.3%	0.032	0.034	0.038	0.035	0.030	0.034
6.6%	0.039	0.040	0.034	0.035	0.037	0.037
6.9%	0.037	0.034	0.042	0.038	0.041	0.038

Avg.-Average of five replicates

bubbles tended to cling to the surfaces. The difference between the maximum specific gravity determined by ASTM D-2041 and that determined by individual constituents gets larger as asphalt content increases due to the presence of more and more air bubbles clinging to the asphalt coated surfaces. The results in Table XV show this difference is statistically significant at the 5% level.

This effect becomes apparent when the percent air voids are determined using the FAA Eastern Region correction factor system. At the optimum asphalt content (6.3%), the difference between the individual constituents maximum theoretical specific gravity and the ASTM D-2041 maximum specific gravity was established as the correction factor. From the experimental results, this value was found to be 0.034. Calculations were made using the average maximum specific gravity obtained by the ASTM D-2041 method and the correction factor of 0.034 to determine the percent air voids at each of the 5 asphalt contents. The value for bulk specific gravity used in the calculations was 2.354 which produced a 3.5% air voids value, the midpoint of the air voids specification limit and the value which would be used to determine the optimum asphalt content. The calculations appear in Appendix D with the resulting air voids values shown in Table XVI.

Calculations were also made using the difference between the individual constituents and ASTM D-2041 values at each asphalt content as the correction factor to be added to the ASTM D-2041 maximum specific gravity. These results are also included in TAble XVI. This difference was smaller at asphalt contents less than optimum and larger at asphalt contents greater than optimum, for the reasons discussed previously (Table IX). This difference in air voids results from the use of the constant correction factor established at the optimum asphalt content, and an adjustment factor which is differenet at each asphalt content. More specifically, a lower value for air voids is determined when the differential correction factor is used on asphalt contents less than optimum because more air bubbles were removed from the specimen in the pycnometer when less asphalt cement was present. Conversely, a higher air voids value is determined using the differential correction factor with asphalt contents above optimum because fewer air bubbles were removed when more asphalt cement was present.

individual constituents method. During air voids analysis the FAA Eastern Region utilizes a correction factor for the maximum specific gravity determined using ASTM D-2041. This correction factor is determined as the difference between the ASTM D-2041 maximum specific gravity and individual constituents maximum theoretical specific gravity at the optimum asphalt content. In this analysis, the maximum specific gravity values determined experimentally were subtracted from the maximum theoretical values at each asphalt content and comparisons were made on the differences. These differnces are given for each asphalt content in Table XIII, and plotted against asphalt content in Figure 11.

The same analysis procedure that was used with the solvent immersion and individual constituents comparison was employed on these data. The t-test was conducted using the UNIVARIATE procedure from SAS (5) to test separately the null hypothesis that the mean of the differences, i.e., the difference between results obtained from the two methods, was zero for each asphalt content. The resulting t-test statistic and probability of test values exceeding the t statistic if the null hypothesis is true are given in Table XIV.

The test indicates that there is a statistically significant difference between the ASTM D-2041 and individual constituents methods at the alpha = 0.05 level for all 5 of the asphalt contents tested. This may result from the fact that, as mentioned previously, the ASTM D-2041 test is performed on a loose specimen suspended in water. In the determination of the volume of the asphalt concrete specimen the water is only accessible to those void spaces between the coated aggregate particles. The air spaces within each aggregate particle below the absorbed layer of asphalt cement are included as part of the volume of the sample. This produces lower estimates of the maximum specific gravity than if those air spaces could be removed in the volume analysis.

The ASTM D-2041 values (Table IV and Figure 6) for maximum specific gravity are less than either solvent immersion or individual constituents. As with the solvent immersion and individual constituents comparison, the second comparison that was conducted between the ASTM D-2041 and individual constituents methods was a one-way ANOVA to test whether asphalt content had an effect on the differences between the 2 methods. The ANOVA procedure generated F statistics to test the null hypothesis that the asphalt content effect was zero, i.e., that the slope of the line of mean differences shown in Figure 12 is zero. The results for the ANOVA procedure, the F statistic and probability of values exceeding the F-test statistic if the null hypothesis is true, are given in Table XV. From the value shown (in Table XV), there is a statistically significant effect of asphalt content on the difference between maximum specific gravities obtained using the ASTM D-2041 and individual constituents methods at the alpha = 0.05 level (Figure 12).

In the effort to remove the air bubbles from the surface of the asphalt sample during the testing procedure, it was observed that for mixtures with less asphalt the air bubbles were removed easily during the 10 minutes under vacuum. For mixtures with more asphalt, the air

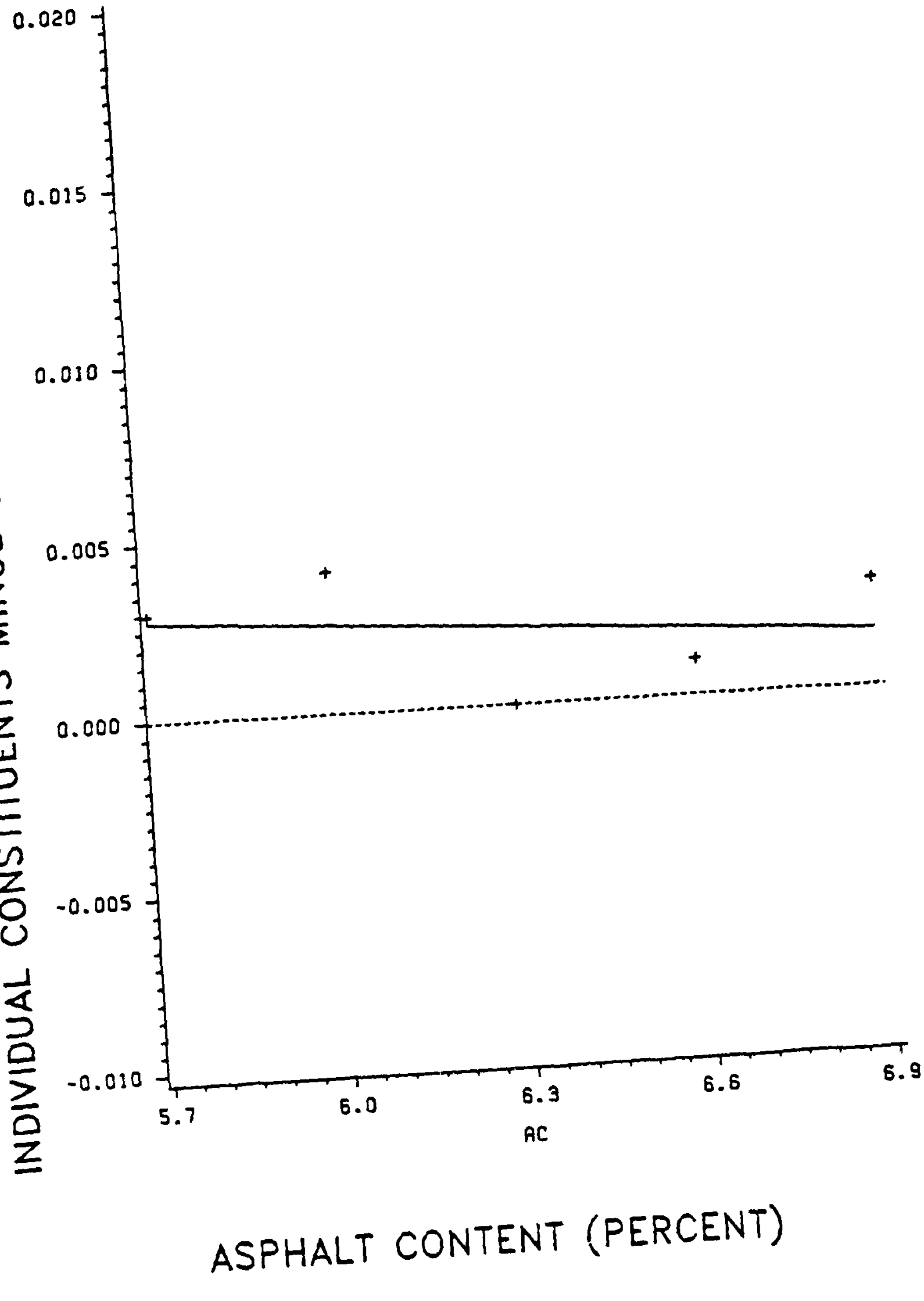


Figure 10. Mean Difference Between Solvent Immersion and Individual Constituents Results versus Asphalt Content

Table XI. t-Test for Comparison of Solvent Immersion and Individual Constituents Results for the Five Asphalt Contents

SAS (5) UNIVARIATE Results		
	Means Difference Analysis	
Asphalt Content	t-Statistic	Prob>|t| [a]
5.7%	2.30089	0.082857
6.0%	2.58492	0.061010
6.3%	0.00000	1.000000
6.6%	1.15865	0.311061
6.9%	2.53546	0.064290

[a] Probability of test values exceeding the absolute t-Statistic

Table XII. F-Test for Effect of Variations in Asphalt Content on Solvent Immersion and Individual Constituents

SAS (5) Analysis of Variance			
Source	df [a]	F Statistic	prob>F [b]
Asphalt Content	4	1.54	0.2300
Error	20		

[a] Degrees of freedom.
[b] Probability of test values exceeding the F-Test statistic.

A mean difference of zero implies that the solvent immerion and individual constituents methods yield the same results. The results, which include the t-test statistic and probability of test values exceeding the t statistic if the null hypothesis is true, are given in Table XI for each asphalt content. The tests indicate that there was no statistically significant difference between the maximum specific gravities obtained using the 2 methods at the alpha = 0.05 significance level, with all probabiities larger than 0.05. However, at the alpha = 0.10 level of significance, the 5.7%, 6.0%, and 6.9% asphalt contents were significantly different.

The trichloroethylene solvent dissolves the asphalt cement that was absorbed by the aggregate particles. The solvent then has access to the void spaces below the absorbed asphalt layer. The void spaces in the aggregate are also filled by the water used to determine the aggregate volume when the apparent specific gravity is determined for use in the individual constituents method. Since the t-test (Table XI) indicates no statistically significant differences between the 2 methods, especially near the optimum asphalt content (6.3% for this gradation), it may be concluded that the solvent immersion and individual constituents methods provide similar results for maxim.m specific gravity since both procedures measure similar volumes for the aggregate.

The second comparison between the maximum specific gravities obtained using the solvent immersion procedure and the individual constituents procedure involved a one-way analysis of variance (ANOVA), using SAS (5), to test whether the difference in results obtained using the 2 methods varies with asphalt content. The analysis procedure generated F statistics to test the null hypothesis that there was no treatment effect (asphalt content) on the difference between results (maximum specific gravity) obtained from solvent immersion and individual constituents procedures. This is analogous to saying that the slope of the mean difference line shown in Figure 10 is zero. The resulting F statistic, and probability of test values exceeding the F statistic if there is truly no treatment effect, is given in Table XII.

The F-test results indicate that there is no statistically significant asphalt content effect at the alpha = 0.05 level for the 2 methods. This indicates that the solvent immersion method is a good indicator of the maximum theoretical specific gravity for an asphalt mixture. Air voids determined using the solvent immersion maximum specific gravity with a correction factor would give similar air voids results as when the maximum theoretical specific gravity obtained by the individual constituents methods was used in air voids analysis.

Comparison of ASTM D-2041 and Individual Constituents Results

A comparative analysis is presented here between the maximum specific gravity determined using the ASTM D-2041 procedure on 5 replicates at 5 asphalt contents and the maximum theoretical specific gravity values determined for the same asphalt contents using the

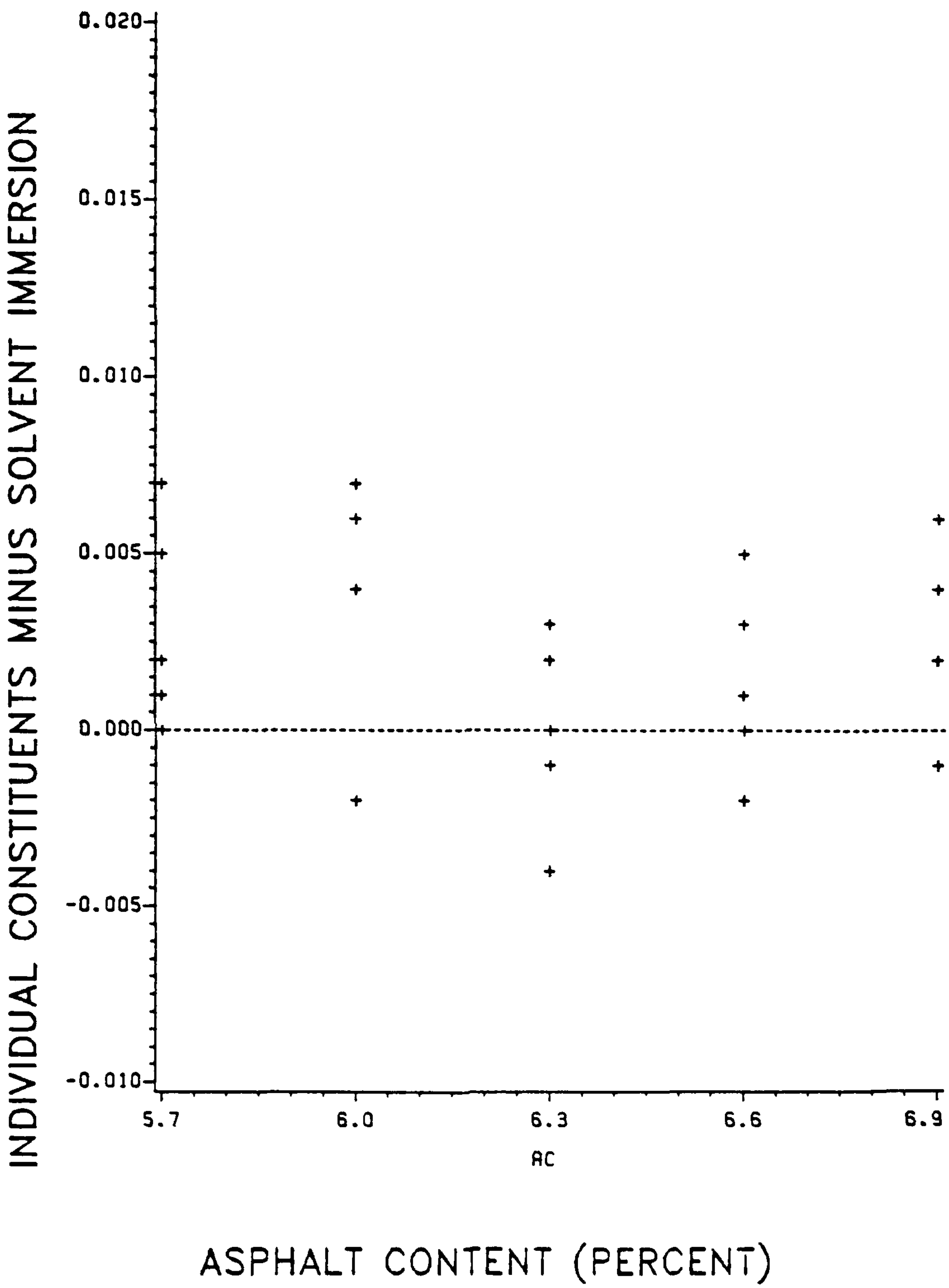


Figure 9. Plot of Differences Between Solvent Immersion and Individual Constituents Results versus Asphalt Content

Table X. Difference Data Between Solvent Immersion and Individual Constituents values for the Five Asphalt Contents

Individual Constituents minus Solvent Immersion						
	Replicate					
Asphalt Content	1	2	3	4	5	Avg.
5.7%	0.001	0.007	0.000	0.002	0.005	0.0030
6.0%	0.007	0.006	0.006	0.004	-0.002	0.0042
6.3%	-0.001	-0.004	0.002	0.003	0.000	0.0000
6.6%	0.003	0.000	-0.002	0.001	0.005	0.0022
6.9%	0.004	0.004	0.006	-0.001	0.002	0.0030

Avg. - Average of Five Replicates

materials, a portion of the asphalt cement is absorbed into the outer pores of the aggregate particles leaving minute void spaces within the individual aggregate particles under the layer of absorbed asphalt. The remainder of the asphalt cement which is not absorbed is the effective asphalt cement used for binding the particles together. Air pockets also occur among the spaces formed by the irregular shapes of the coated aggregate particles.

The difference in the results obtained from the 2 procedures may be attributed to the trichloroethylene solvent dissolving all the asphalt cement in a test specimen, thus gaining access to the void spaces in the aggregate within the layer of the absorbed asphalt cement as well as the void spaces between the particles.

The ASTM D-2041 procedure uses distilled water that can not penetrate into the void spaces in the aggregate that are covered by the absorbed layer of asphalt cement. When placed under vacuum, the distilled water can only occupy those air voids between the coated aggregate particles. The result is that the volume of the asphalt mixture determined by the ASTM D-2041 procedure is greater than that determined by solvent immersion for the same sample of material. When maximum specific gravity calculations are made, the weight of the material tested is divided by a larger volume when determined by the ASTM D-2041 procedure than that volume determined by the solvent immersion procedure. Since the weight is the same and the volume is greater, the resulting ASTM D-2041 specific gravities are less. The maximum specific gravity determined by ASTM D-2041 is consistently less than the solvent immersion maximum specific gravity for each asphalt content (Table VII and Figure 6).

Comparison of Solvent Immersion and Individual Constituents Results

This section contains the comparisons between the maximum specific gravities from 5 replicates of 5 asphalt contents determined by the solvent immersion method and the maximum theoretical specific gravity determined using the individual constituents method for the same aggregate and asphalt cement materials at the same 5 asphalt contents. The individual constituents method is used during mix design stages to determine maximum theoretical specific gravity used in air voids analysis, while the solvent immersion procedure is used with a correcton factor during production to determine maximum specific gravities used in air voids analysis. This analysis was conducted on data obtained by subtracting maximum specific gravities obtained from solvent immersion from the maximum theoretical specific gravities obta[illegible] from the individual constituents method at each asphalt content. The differences resulting from the 2 methods are shown in Table X and in Figure 9.

Comparisons were made individually between the solvent immersion maximum specific gravity and indivdual constituents maximum theoretical specific gravity at the 5 asphalt contents (5.7%, 6.0%, 6.3%, 6.6%, and 6.9%). A t-test was conducted using the SAS (5) UNIVARIATE procedure to test the null hypothesis that the mean of the differences was zero.

Table IX. **Comparison of Solvent Immersion and ASTM D-2041 Methods for all Five Asphalt Contents**

Comparison of Specific Gravities Obtained by Solvent Immersion and ASTM D-2041 Procedures				
	Variance Analysis		Means Analysis	
Asphalt Content	F-Statistic	Prob>F[a]	t-Statistic	Prob>|t|[b]
5.7%	1.49	0.7067	-11.5583	0.0001
6.0%	1.42	0.7426	-11.9737	0.0001
6.3%	1.23	0.8478	-18.4945	0.0001
6.6%	1.12	0.9131	-21.4287	0.0001
6.9%	1.47	0.7173	-19.0312	0.0001

[a] Probability of test values exceeding the F statistic.
[b] Probability of test values exceeding the absolute t statistic.

immersion maximum specific gravities cluster near the individual constituents maximum theoretical specific gravities, while the ASTM D-2041 maximum specific gravities are noticeably lower for each asphalt content.

Figure 7 shows that the maximum specific gravity decrease with increasing asphalt content may have a linear relationsip. From the plot of the standard deviation of the maximum specific gravity results versus asphalt content (Figure 8), it is indicated that the variabilty of the solvent immersion and ASTM D-2041 methods is reasonably consistent as asphalt content changes.

Copmparison of Solvent Immersion and ASTM D-2041 Results

During production of asphalt concrete on the FAA Eastern Region projects, the maximum specific gravity was determined using either the solvent immersion procedure or the ASTM D-2041 procedure. The analysis of data obtained from maximum specific gravity results of 5 replicates, each consisting of 5 asphalt contents, determined by solvent immersion and ASTM D-2041 is presented in this section.

The null hypothesis, to be tested at each asphalt content, was that the means for the 2 groups of data (maximum specific gravities obtained from solvent immersion and ASTM D-2041) are equal, assuming equal but unknown variance. Therefore, the first analysis necessary is to determine whether the variances of the 2 procedures are equal for each asphalt content. The TTEST procedure in SAS (5) was conducted on the 2 groups of data, first, using an F-test to test for equality of variances, and then using a sample t-test to test for equal means. Table IX presents the following results for each aspahlt content:

1. the F-test statistic and probability of F values exceeding the F statistic assuming that the true variances of the 2 procedures are equal, and,

2. the sample t-test statistic and the probability of t values exceeding the absolute t statistic if the true means are equal.

From the results shown in Table IX, the probability of an F-statistic exceeding the F value for each asphalt content is greater than 0.05 (alpha = 0.05), or 5 percent level of significance. This indicates that there is not enough evidence to reject the null hypotheses that the variances of the 2 procedures are equal at the 5 percent level of significance. From the t-test statistics and associated exceedence probabilities in Table IX, it is noted that all probabilities are much less than 0.05. This indicates that the null hypothesis of equal means can be rejected at the alpha = 0.05 level for each of the 5 asphalt contents.

Therefore, a statistically significant difference exists between maximum specific gravities obtained from solvent immersion and those obtained from ASTM D-2041 procedures. During the mixing of asphaltic

Table XV. F-Test for effect of Variations in Asphalt Content on ASTM D-2041 and Individual Constituents

SAS (5) Analysis of Variance			
Source	df [a]	F Statistic	prob>F [b]
Asphalt Content	4	12.46	0.0001
Error	20		

[a] Degrees of freedom.
[b] Probability of test values exceeding the F-Test statistic.

Table XVI. Summary of Air Voids Results for the Five Asphalt Contents and Individual Constituents

Asphalt Content	Air Voids (%) with FAA Correction (0.034)	Air Voids (%) with Difference as Correction	Difference
5.7%	4.62	4.35	0.27
6.0%	4.07	3.92	0.15
6.3%	3.49	3.49	0.00
6 6%	2.93	3.05	-0.12
6.9%	2.49	2.65	-0.16

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

A laboratory analysis was conducted, first of all, to obtain the values for apparent specific gravity used in the individual constituents method, and then to prepare and test 5 replicates each with 5 asphalt contents using the solvent immersion and the ASTM D-2041 methods. The purpose of this research was to compare the maximum specific gravity obtained by each of the 3 methods and then to measure what effect changes in asphalt content produced on the maximum specific gravity results.

Conclusions

The following conclusions were reached from the laboratory analysis to compare the maximum specific gravity used in air voids analysis.

1. A statistically significant difference exists between the maximum specific gravity determined using the solvent immersion method and that determined using the ASTM D-2041 method at each asphalt content, however, the relative variability between the two methods was the same.

2. There is no statistically significant difference between maximum specific gravities obtained using the solvent immersion and individual constituents methods at the alpha = 0.05 significance level. At asphalt contents different from optimum, however, there was a statistical difference at the alpha = 0.10 significance level.

3. Changes in asphalt content did not statistically affect the differences between the solvent immersion and individual constituents maximum specific gravity results.

4. At each asphalt content, there was a statistically significant difference between results obtained using the ASTM D-2041 method and the individual constituents method.

5. There is a statistically significant effect of asphalt content on the difference between results obtained from the ASTM D-2041 method and the individual constituents method. This difference was found to increase with increasing asphalt content.

6. Using the correction factor system employed by the FAA Eastern Region with the ASTM D-2041 method, the resulting air voids values were higher at asphalt contents below optimum and

lower at asphalt contents above optimum than when the average difference between the 2 methods was used as a correction factor.

These conclusions are applicable for the conditions, i.e., asphalt cement, aggregate gradation, asphalt content, and test time, used in this laboratory investigation.

Additional research should be conducted to further investigate the use of the ASTM D-2041 procedure with the current correction factor for maximum specific gravity determination used in air voids analysis. Testing should be conducted on samples with different types of asphalt cement. Different gradations and the absorption properties of the aggregates should also be investigated. Finally, the amount of time the sample is exposed to the partial vacuum, for removal of air bubbles, should be considered.

Recommendations

The conclusions stated above indicate that similar results are not obtained from the 3 methods for maximum specific gravity determination that were investigated. It is recommended that the solvent immersion method be eliminated from use. While this method provided results that were closer to the individual constituents approach currently used by the FAA for job mix formula determination, solvent immersion is not widely used. The ASTM D-2041 procedures are much more commonly employed. Since the solvent immersion and ASTM D-2041 methods provide statistically different results, it is not appropriate to allow the use of both methods in the same specification unless separate acceptance limits are considered.

The ASTM D-2041 approach, as currently used by the FAA Eastern Region, requires the development of a correction factor to convert the ASTM D-2041 results to equivalent individual constituents values. This research has shown that the necessary correction factor varies with the asphalt content of the mixture. To avoid the use of a correction factor altogether, it is recommended that the maximum specific gravity for job mix formula determination be established using the ASTM D-2041 procedure. In this way, the same test procedure will be used in determining the job mix formula and for the field control tests, and no correction factor should be required.

If it is desired to maintain the use of the individual constituents approach based on apparent specific gravities of the constituents for job mix formula determination, then the solvent immersion method is preferable to the ASTM D-2041 method since it more closely approximates the individual constituents values. The solvent immersion method, however, suffers from its limited use and the required exposure of the laboratory technicians to the solvent that is used.

The use of the ASTM D-2041 method for establishing maximum specific gravity in job mix formula calculations is similar to the effective specific gravity procedures recommended by the Asphalt Institute in its publication Mix Design Methods for Asphalt Concrete, (MS-2) (11). This

approach eliminates the current need to use a correction factor and should lead to more consistent results between the job mix formula and the field quality control and acceptance tests.

BIBLIOGRAPHY

1. "Standard Test Method for Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface Dry Specimens", ASTM D-2726-73, Annual Book of ASTM Standards, Part 15, American Society for Testing and Materials, Philadelphia, PA, 1982, p. 794.

2. Burati, J.L., Jr., and J. H. Willenbrock, Acceptance Criteria for Bituminous Surface Course on Civil Airport Pavements. Report No. FAA-RD-79-89. National Technical Information Service, 1979.

3. "Standard Test Method for Theoretical Maximum Specific Gravity of Bituminous Paving Mixtures", ASTM D-2041-78, Annual Book of ASTM Standards, Part 15, American Society for Testing and Materials, Philadelphia, PA, 1982, p. 530.

4. Laboratory Procedures Manual, Federal Aviation Administration, Eastern Region, Washington, DC, January 1981.

5. SAS User's Guide: Basics, 1982 Edition, SAS Institute Inc., Cary, NC, 1982.

6. Burati, J.L., Brantley, G.D. and Morgan, F.W., Final Report, "Field Validation of Statistically-Based Acceptance Plan for Bituminous Airport Pavements, Volume 1: Correlation Analysis of Marshall Properties of Laboratory-Compacted Specimens," submitted to the Federal Aviation Administration, Washington, DC, May 1984.

7. "Standard Test Method for Specific Gravity and Absorption of Coarse Aggregate," ASTM C-127-81, Annual Book of ASTM Standards, Part 15, American Society for Testing and Materials, Philadelphia, PA, 1982, p.24.

8. "Standard Test Method for Specific Gravity and Absorption of Fine Aggregate," ASTM C-128-81, Annual Book of ASTM Standards, Part 15, American Society for Testing and Materials, Philadelphia, PA, 1982, p.28.

9. Procedure Manual, Yale Pycnometer Co. Inc., Soiltest Inc., 2205 Lee St., Evanston, Ill.

10. Graybill, F.A., An Introduction to Linear Statistical Models, Vol. 1, McGraw-Hill.

11. Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types, The Asphalt Institute Manual Series No. 2, (MS-2), College Park, MD, May 1984.

12. Burati, J.L., Seward, J.D. and Busching, H.W., Final Report, "Field Validation of Statistically-Based Acceptance Plan for Bituminous Airport Pavements, Volume 2: Statistical Analysis of Marshall Properties of Plant-Produced Bituminous Materials," submitted to the Federal Aviation Administration, Washington, DC, May 1984.

Appendix A

Maximum Theoretical Specific Gravity Calculations by Individual Constituents

Table A-I. Maximum Theoretical Specific Gravity for 5.7% Asphalt Content

Individual Constituent		
Aggregate	Percent by Total Weight	Apparent Specific Gravity
Coarse (-3/4, +No.4)	31.6	2.693
Fine - Limestone (-No.4, +Pan)	43.9	2.672
Fine - Nat. Sand (-No.4, +Pan)	18.8	2.721
Asphalt Cement	5.7	1.024

$$MTSG = \frac{P1 + P2 + P3 + Pb}{\frac{P1}{G1} + \frac{P2}{G2} + \frac{P3}{G3} + \frac{Pb}{Gb}}$$

where

MTSG = maximum theoretical specific gravity,

P1,P2,P3 = percent by weight of aggregate,

G1,G2,G3 = apparent specific gravity of aggregate,

Pb = percent by weight of bitumen,

Gb = specific gravity of bitumen.

Substitution of data for 5.7% asphalt content yields:

$$MTSG = \frac{31.6 + 43.9 + 18.8 + 5.7}{\frac{31.6}{2.693} + \frac{43.9}{2.672} + \frac{18.8}{2.721} + \frac{5.7}{1.024}}$$

$$= \frac{100}{11.73 + 16.43 + 6.91 + 5.57}$$

$$= 2.461$$

Table A-II. Maximum Theoretical Specific Gravity for 6.0% Asphalt Content

Individual Constituent		
Aggregate	Percent by Total Weight	Apparent Specific Gravity
Coarse (-3/4, +No.4)	31.5	2.693
Fine - Limestone (-No.4, +Pan)	43.7	2.672
Fine - Nat. Sand (-No.4, +Pan)	18.8	2.721
Asphalt Cement	6.0	1.024

$$MTSG = \frac{P1 + P2 + P3 + Pb}{\frac{P1}{G1} + \frac{P2}{G2} + \frac{P3}{G3} + \frac{Pb}{Gb}}$$

where

MTSG = maximum theoretical specific gravity,

P1,P2,P3 = percent by weight of aggregate,

G1,G2,G3 = apparent specific gravity of aggregate,

Pb = percent by weight of bitumen,

Gb = specific gravity of bitumen.

Substitution of data for 6.0% asphalt content yields:

$$MTSG = \frac{31.5 + 43.7 + 18.8 + 6.0}{\frac{31.5}{2.693} + \frac{43.7}{2.672} + \frac{18.8}{2.721} + \frac{6.0}{1.024}}$$

$$= \frac{100}{11.70 + 16.35 + 6.91 + 5.86}$$

$$= 2.450$$

Table A-III. Maximum Theoretical Specific Gravity for 6.3% Asphalt Content

Individual Constituent		
Aggregate	Percent by Total Weight	Apparent Specific Gravity
Coarse (-3/4, +No.4)	31.4	2.693
Fine - Limestone (-No.4, +Pan)	43.6	2.672
Fine - Nat. Sand (-No.4, +Pan)	18.7	2.721
Asphalt Cement	6.3	1.024

$$MTSG = \frac{P1 + P2 + P3 + Pb}{\frac{P1}{G1} + \frac{P2}{G2} + \frac{P3}{G3} + \frac{Pb}{Gb}}$$

where

MTSG = maximum theoretical specific gravity,

P1,P2,P3 = percent by weight of aggregate,

G1,G2,G3 = apparent specific gravity of aggregate,

Pb = percent by weight of bitumen,

Gb = specific gravity of bitumen.

Substitution of data for 6.3% asphalt content yields:

$$MTSG = \frac{31.4 + 43.6 + 18.7 + 6.3}{\frac{31.4}{2.693} + \frac{43.6}{2.672} + \frac{18.7}{2.721} + \frac{6.3}{1.024}}$$

$$= \frac{100}{11.66 + 16.32 + 6.87 + 6.15}$$

$$= 2.439$$

Table A-IV. Maximum Theoretical Specific Gravity for 6.6% Asphalt Content

Individual Constituent		
Aggregate	Percent by Total Weight	Apparent Specific Gravity
Coarse (-3/4, +No.4)	31.3	2.693
Fine - Limestone (-No.4, +Pan)	43.4	2.672
Fine - Nat. Sand (-No.4, +Pan)	18.7	2.721
Asphalt Cement	6.6	1.024

$$MTSG = \frac{P1 + P2 + P3 + Pb}{\frac{P1}{G1} + \frac{P2}{G2} + \frac{P3}{G3} + \frac{Pb}{Gb}}$$

where

MTSG = maximum theoretical specific gravity,

P1,P2,P3 = percent by weight of aggregate,

G1,G2,G3 = apparent specific gravity of aggregate,

Pb = percent by weight of bitumen,

Gb = specific gravity of bitumen.

Substitution of data for 6.6% asphalt content yields:

$$MTSG = \frac{31.3 + 43.4 + 18.7 + 6.6}{\frac{31.3}{2.693} + \frac{43.4}{2.672} + \frac{18.7}{2.721} + \frac{6.6}{1.024}}$$

$$= \frac{100}{11.62 + 16.24 + 6.87 + 6.45}$$

$$= 2.428$$

Table A-V. Maximum Theoretical Specific Gravity for 6.9% Asphalt Content

Individual Constituent		
Aggregate	Percent by Total Weight	Apparent Specific Gravity
Coarse (-3/4, +No.4)	31.2	2.693
Fine - Limestone (-No.4, +Pan)	43.3	2.672
Fine - Nat. Sand (-No.4, +Pan)	18.6	2.721
Asphalt Cement	6.9	1.024

$$MTSG = \frac{P1 + P2 + P3 + Pb}{\frac{P1}{G1} + \frac{P2}{G2} + \frac{P3}{G3} + \frac{Pb}{Gb}}$$

where

MTSG = maximum theoretical specific gravity,

P1,P2,P3 = percent by weight of aggregate,

G1,G2,G3 = apparent specific gravity of aggregate,

Pb = percent by weight of bitumen,

Gb = specific gravity of bitumen.

Substitution of data for 6.9% asphalt content yields:

$$MTSG = \frac{31.2 + 43.3 + 18.6 + 6.9}{\frac{31.2}{2.693} + \frac{43.3}{2.672} + \frac{18.6}{2.721} + \frac{6.9}{1.024}}$$

$$= \frac{100}{11.59 + 16.21 + 6.84 + 6.74}$$

$$= 2.418$$

Appendix B

Sample Calculations for Solvent Immersion and ASTM D-2041

Table B-I. Solvent Immerson Sample Calculation

Replicate #1, Asphalt Content 5.7%		
A)	Flask	372.2 g.
B)	Flask and Solvent @ 77°F	2026.5 g.
D)	Flask and Sample	1619.9 g.
E)	Flask, Sample, Solvent @ 77°F	2538.9 g.
C)	Trichloroethylene - specific gravity	1.45

$$MSG = \frac{(D-A) \times C}{(B+D) - (E+A)}$$

where

MSG = maximum specific gravity

A = weight flask, g.,

B = weight flask and solvent @ 77 °F, g.,

C = specific gravity of solvent = 1.45,

D = weight of flask and mix, g.,

E = weight flask and solvent and mix, g.

Substitution of data from replicate 1 yields:

$$MSG = \frac{(1619.9 - 372.2) \times 1.45}{(2026.5 + 1619.9) - (372.2 + 2538.9)}$$

$$= 2.460$$

Table D-I. Percent Air Voids for 5.7% Asphalt Content

Air Voids Calculation					
ASTM D-2041			MSG	=	2.434
			BSG	=	2.354
Correction Factor @ 6.3% (1)			A.C.	=	0.034
Differential Correction Factor @ 5.7% (2)			A.C.	=	0.027

ASTM D-2041 MSG		2.434		2.434
+ Correction Factor	(1)	+0.034	(2)	+0.027
Adjusted MSG		2.468		2.461

Air Voids (1) = 100 - 100 (BSG / MSG)

= 100 - 100 (2.354 / 2.468)

= 4.62%

Air Voids (2) = 100 - 100 (BSG / MSG)

= 100 - 100 (2.354 / 2.461)

= 4.35%

Appendix D

Percent Air Voids Calculations for all Five Asphalt Contents

Table C-X. Solvent Immersion Data - Replicate 5

Solvent Immersion -- Replicate 5					
	Asphalt Content				
Test Value	5.7%	6.0%	6.3%	6.6%	6.9%
Flask,g.	372.2	372.2	372.2	372.2	372.1
Flask+Solvent,g.	2026.5	2026.5	2026.6	2026.5	2026.6
Flask+Mix.,g.	1649.8	1635.5	1627.1	1622.3	1629.8
Flask.+Mix.+Sol.,g.	2542.9	2542.8	2535.5	2528.6	2529.5
Sp.Gr. Solv.	1.45	1.45	1.45	1.45	1.45
MSG	2.456	2.452	2.439	2.423	2.416

MSG - maximum specific gravity

Table C-IX. Solvent Immersion Data - Replicate 4

Solvent Immersion -- Replicate 4					
	Asphalt Content				
Test Value	5.7%	6.0%	6.3%	6.6%	6.9%
Flask,g.	372.2	372.2	372.2	372.2	372.2
Flask+Solvent,g.	2026.6	2026.6	2026.6	2026.6	2026.6
Flask+Mix.,g.	1639.7	1611.8	1628.5	1619.0	1616.3
Flask.+Mix.+Sol.,g.	2546.7	2531.4	2535.1	2528.5	2525.0
Sp.Gr. Solv.	1.45	1.45	1.45	1.45	1.45
MSG	2.459	2.446	2.436	2.427	2.419

MSG - maximum specific gravity

Table C-VIII. Solvent Immersion Data - Replicate 3

Solvent Immersion -- Replicate 3					
	Asphalt Content				
Test Value	5.7%	6.0%	6.3%	6.6%	6.9%
Flask,g.	372.2	372.2	372.2	372.2	372.2
Flask+Solvent,g.	2026.6	2026.6	2026.8	2026.8	2026.6
Flask+Mix.,g.	1625.5	1650.0	1617.6	1636.4	1623.2
Flask.+Mix.+Sol.,g.	2541.5	2545.1	2531.2	2529.7	2525.5
Sp.Gr. Solv.	1.45	1.45	1.45	1.45	1.45
MSG	2.461	2.444	2.437	2.430	2.412

MSG - maximum specific gravity

Table C-VII. Solvent Immersion Data - Replicate 2

Solvent Immersion -- Replicate 2					
	Asphalt Content				
Test Value	5.7%	6.0%	6.3%	6.6%	6.9%
Flask,g.	372.2	372.2	372.3	372.2	372.2
Flask+Solvent,g.	2026.5	2026.5	2026.6	2026.5	2026.5
Flask+Mix.,g.	1624.7	1618.1	1636.8	1627.0	1629.9
Flask.+Mix.+Sol.,g.	2538.9	2533.3	2540.6	2532.0	2528.7
Sp.Gr. Solv.	1.45	1.45	1.45	1.45	1.45
MSG	2.454	2.444	2.443	2.428	2.414

MSG - maximum specific gravity

Table C-VI. Solvent Immersion Data - Replicate 1

Solvent Immersion -- Replicate 1					
	Asphalt Content				
Test Value	5.7%	6.0%	6.3%	6.6%	6.9%
Flask,g.	372.2	372.2	372.2	372.2	372.2
Flask+Solvent,g.	2026.5	2026.5	2026.6	2026.5	2026.6
Flask+Mix.,g.	1619.9	1626.6	1618.2	1655.1	1618.2
Flask.+Mix.+Sol.,g.	2538.9	2536.5	2532.3	2542.4	2532.3
Sp.Gr. Solv.	1.45	1.45	1.45	1.45	1.45
MSG	2.460	2.443	2.440	2.425	2.414

MSG - maximum specific gravity

Table C-V. ASTM D-2041 Data - Replicate 5

ASTM D-2041 (Type D) -- Replicate 5					
	Asphalt Content				
Test Value	5.7%	6.0%	6.3%	6.6%	6.9%
Tare+Material,g.	6009	6007	6012	6013	6015
Tare,g.	2	2	2	4	2
Sample,g.	6007	6005	6010	6009	6013
Pyc+Water,g.	16317	16315	16312	16314	16319
Total,g.	22325	22320	22322	22323	22332
Water+Pyc+Mix,g.	19868	19842	19836	19818	19808
Water Disp.,g.	2457	2478	2486	2505	2524
Temp°F	96	98	100	99	94
Asphalt Corr.	-1.10	-1.30	-1.48	-1.46	-1.28
Adjusted Wt.,g.	2455.9	2476.7	2484.5	2503.5	252875
ASTM Curve R	0.9968	0.9964	0.9960	0.9962	0.9972
MSG	2.438	2.416	2.409	2.391	2.377

MSG - maximum specific gravity

Table C-IV. ASTM D-2041 Data - Replicate 4

ASTM D-2041 (Type D) -- Replicate 4					
	Asphalt Content				
Test Value	5.7%	6.0%	6.3%	6.6%	6.9%
Tare+Material,g.	6015	6002	6013	6005	6024
Tare,g.	2	3	4	2	5
Sample,g.	6013	5999	6009	6003	6019
Pyc+Water,g.	16320	16314	16316	16315	16315
Total,g.	22333	22313	22325	22318	22334
Water+Pyc+Mix,g.	19869	19841	19833	19817	19815
Water Disp.,g.	2464	2472	2492	2501	2520
Temp°F	93	99	97	98	98
Asphalt Corr.	-0.96	-1.36	-1.30	-1.42	-1.50
Adjusted Wt.,g.	2463.0	2470.6	2490.7	2499.6	2519.5
ASTM Curve R	0.9975	0.9962	0.9966	0.9964	0.9964
MSG	2.435	2.419	2.404	2.393	2.380

MSG - maximum specific gravity

Table C-III. ASTM D-2041 Data - Replicate 3

ASTM D-2041 (Type D) -- Replicate 3					
	Asphalt Content				
Test Value	5.7%	6.0%	6.3%	6.6%	6.9%
Tare+Material,g.	6013	6013	6003	6014	6009
Tare,g.	3	1	1	3	2
Sample,g.	6010	6012	6002	6011	6007
Pyc+Water,g.	16311	16318	16317	16317	16320
Total,g.	22321	22330	22319	22328	22327
Water+Pyc+Mix,g.	19858	19856	19826	19824	19804
Water Disp.,g.	2463	2474	2493	2504	2523
Temp°F	101	95	96	96	93
Asphalt Corr.	-1.38	-1.14	-1.24	-1.28	-1.16
Adjusted Wt.,g.	2461.6	2472.9	2491.8	2502.7	2521.8
ASTM Curve R	0.9958	0.9970	0.9968	0.9968	0.9974
MSG	2.431	2.424	2.401	2.394	2.376

MSG - maximum specific gravity

Table C-II. ASTM D-2041 Data - Replicate 2

ASTM D-2041 (Type D) -- Replicate 2					
	Asphalt Content				
Test Value	5.7%	6.0%	6.3%	6.6%	6.9%
Tare+Material,g.	6005	6007	6014	6009	6004
Tare,g.	3	1	3	1	2
Sample,g.	6002	6006	6011	6008	6002
Pyc+Water,g.	16321	16315	16318	16317	16315
Total,g.	22323	22321	22329	22325	22317
Water+Pyc+Mix,g.	19858	19849	19836	19818	19807
Water Disp.,g.	2465	2472	2493	2509	2510
Temp°F	92	98	95	96	98
Asphalt Corr.	-0.9	-1.3	-1.18	-1.30	-1.46
Adjusted Wt.,g.	2464.1	2470.7	2491.8	2507.7	2508.5
ASTM Curve R	0.9975	0.9964	0.9970	0.9968	0.9964
MSG	2.430	2.422	2.405	2.388	2.384

MSG - maximum specific gravity

Table C-I. ASTM D-2041 Data - Replicate 1

ASTM D-2041 (Type D) -- Replicate 1					
	Asphalt Content				
Test Value	5.7%	6.0%	6.3%	6.6%	6.9%
Tare+Material,g.	6005	6007	6003	6009	6008
Tare,g.	2	2	1	1	1
Sample,g.	6003	6005	6002	6008	6007
Pyc+Water,g.	16316	16316	16317	16317	16320
Total,g.	22319	22321	22319	22325	22327
Water+Pyc+Mix,g.	19863	19848	19831	19817	19809
Water Disp.,g.	2456	2473	2488	2508	2518
Temp°F	97	97	96	96	94
Asphalt Corr.	-1.16	-1.22	-1.24	-1.30	-1.16
Adjusted Wt.,g.	2454.8	2471.8	2486.8	2506.7	2517.8
ASTM Curve R	0.9975	0.9964	0.9970	0.9968	0.9964
MSG	2.437	2.421	2.406	2.389	2.381

MSG - maximum specific gravity

Appendix C

Maximum Specific Gravity Data

Table B-II. ASTM D-2041 Sample Calculation

Replicate #1, Asphalt Content 5.7%		
A)	Sample in Air	6003 g.
F)	Pycnometer and Water @ 97°F	16,316 g.
G)	Pycnometer, Water, Sample @ 97°F	19,863 g.
H)	Asphalt Correction @ 97°F, 5.7% A.C.	-1.16
K)	dw/.9970	.9975

$$MSG = \frac{A}{(A+F) - (G+H)} \times \frac{dw}{.9970}$$

where

MSG = maximum specific gravity

A = mass of dry sample in air, g.,

F = mass of pycnometer with water at test temperature, g.,

G = mass of pycnometer with water and sample at test temperature, g.,

H = correction for thermal expansion (Figure. 4) ASTM D-2041,

dw = density of water at test temperature Curve D (Figure. 5) ASTM D-2041,

.9970 = density of water at 77 °F.

Substitution of data from Replicate 1 yields:

$$MSG = \frac{6003}{(6003 + 16316) - (19863 - 1.16)} \times .9975$$

$$= 2.437$$

Table D-II. Percent Air Voids for 6.0% Asphalt Content

Air Voids Calculation

ASTM D-2041	MSG	=	2.420
	BSG	=	2.354
Correction Factor @ 6.3% (1) A.C.		=	0.034
Differential Correction Factor @ 5.7% (2) A.C.		=	0.030

ASTM D-2041 MSG		2.420		2.420
+ Correction Factor	(1)	+0.034	(2)	+0.030
Adjusted MSG		2.454		2.450

$$\text{Air Voids (1)} = 100 - 100\ (\text{BSG} / \text{MSG})$$
$$= 100 - 100\ (2.354 / 2.454)$$
$$= 4.07\%$$

$$\text{Air Voids (2)} = 100 - 100\ (\text{BSG} / \text{MSG})$$
$$= 100 - 100\ (2.354 / 2.450)$$
$$= 3.92\%$$

Table D-III. Percent Air Voids for 6.3% Asphalt Content

Air Voids Calculation

ASTM D-2041	MSG	=	2.405
	BSG	=	2.354
Correction Factor @ 6.3% (1)	A.C.	=	0.034
Differential Correction Factor @ 5.7% (2)	A.C.	=	0.034

ASTM D-2041 MSG		2.405		2.405
+ Correction Factor	(1)	+0.034	(2)	+0.027
Adjusted MSG		2.439		2.439

Air Voids (1) = 100 - 100 (BSG / MSG)

= 100 - 100 (2.354 / 2.439)

= 3.49%

Air Voids (2) = 100 - 100 (BSG / MSG)

= .00 - 100 (2.354 / 2.439)

= 3.49%

Table D-IV. Percent Air Voids for 6.6% Asphalt Content

Air Voids Calculation				
	ASTM D-2041	MSG	=	2.391
		BSG	=	2.354
Correction Factor @ 6.3% (1) A.C.			=	0.034
Differential Correction Factor @ 5.7% (2) A.C.			=	0.037

ASTM D-2041 MSG		2.391		2.391
+ Correction Factor	(1)	+0.034	(2)	+0.037
Adjusted MSG		2.425		2.428

$$\begin{aligned} \text{Air Voids (1)} &= 100 - 100\ (\text{BSG} / \text{MSG}) \\ &= 100 - 100\ (2.354 / 2.425) \\ &= 2.93\% \end{aligned}$$

$$\begin{aligned} \text{Air Voids (2)} &= 100 - 100\ (\text{BSG} / \text{MSG}) \\ &= 100 - 100\ (2.354 / 2.428) \\ &= 3.05\% \end{aligned}$$

Table D-V. Percent Air Voids for 6.9% Asphalt Content

Air Voids Calculation

ASTM D-2041 MSG	=	2.380
BSG	=	2.354
Correction Factor @ 6.3% (1) A.C.	=	0.034
Differential Correction Factor @ 5.7% (2) A.C.	=	0.038

ASTM D-2041 MSG		2.380		2.380
+ Correction Factor	(1)	+0.034	(2)	+0.038
Adjusted MSG		2.414		2.418

$$\text{Air Voids (1)} = 100 - 100\,(\,BSG\,/\,MSG\,) = 100 - 100\,(\,2.354\,/\,2.414\,) = 2.49\%$$

$$\text{Air Voids (2)} = 100 - 100\,(\,BSG\,/\,MSG\,) = 100 - 100\,(\,2.354\,/\,2.418\,) = 2.65\%$$

END

FILMED

6-85

DTIC